The Engineer

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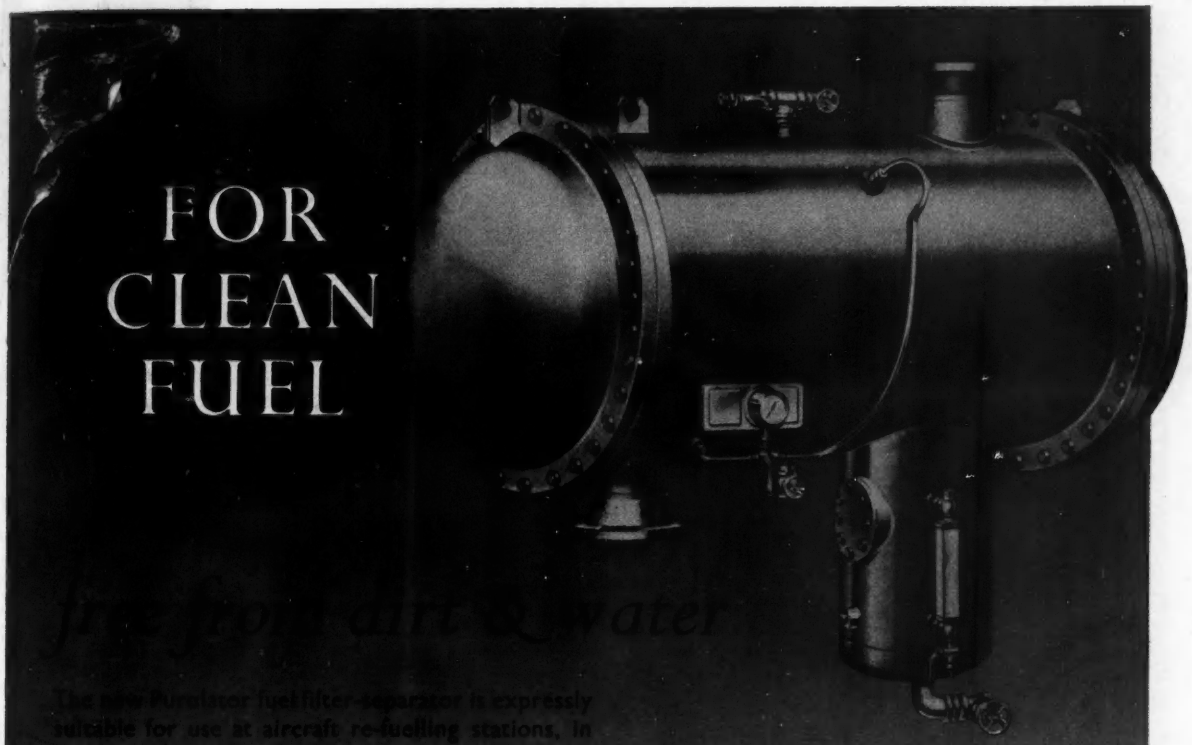

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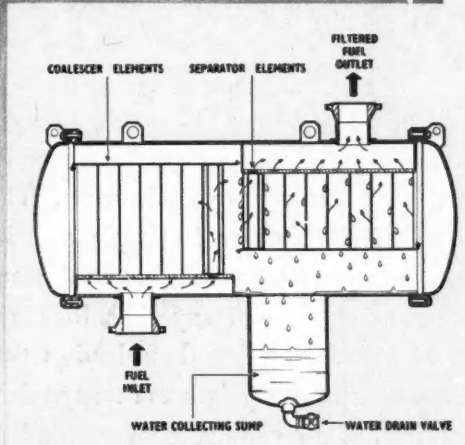

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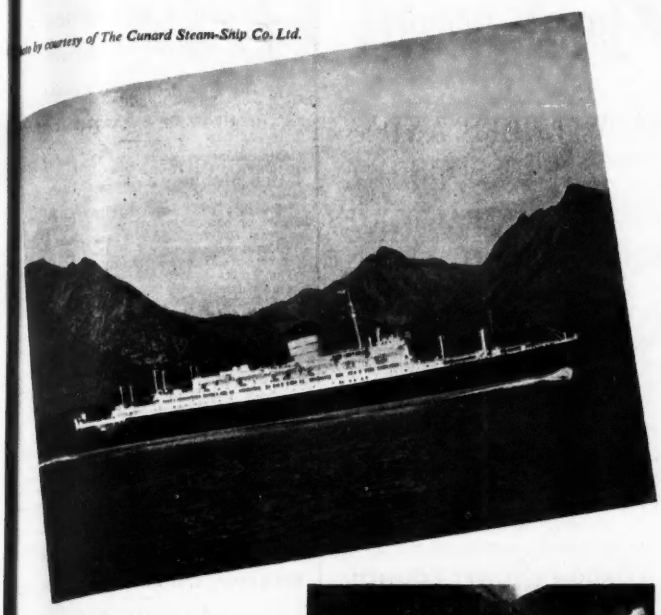
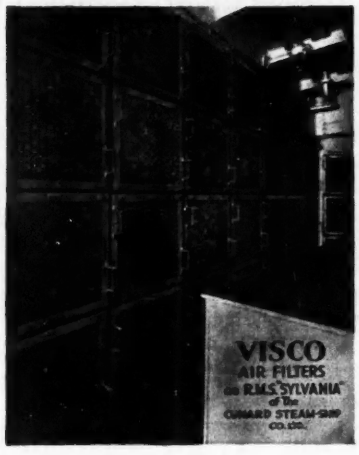


Top: The Cunard Steam-Ship Co. Ltd., R.M.S. "Sylvania".



Right: Part of the "Visco" oil-wetted type Air Filters incorporated in the ventilating system of the new Cunarder R.M.S. "Sylvania".

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THE ENGINEER

ESTABLISHED 1856

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Vol. 204 No. 5307

OCTOBER 11, 1957

Published every Friday Registered as a Newspaper

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SUBSCRIPTIONS

U.K. and ABROAD £5 10. 0. per annum, including postage (CANADA £5 5. 0.) Single copies 2s. each, plus 9d. postage. Also on sale at newsagents.

'THE ENGINEER' BUYERS GUIDE

Published annually. One FREE copy is sent to all direct postal subscribers on publication and delivered by newsagents to all regular readers. Additional copies are obtainable at 7s. 6d. each. Postage 1s. 9d. extra.

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Published by
MORGAN BROTHERS (PUBLISHERS) LTD.,
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Application forms from Secretary at College, Poplar High Street, E.14, to be returned by 25th October, 1957. (1854.) E8711

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E. R.

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		Main Location	*Auctioneers*
October 14–15	Vehicles and miscellaneous stores, including electrical stores, M.T. spares	Central Ordnance Depot, Bicester, Oxon	MIDLAND MARTS, LTD. (Dept. L), Market Square, Bicester, Oxon. (Tel.: 73.)
October 17	Plant and machinery,	M.O.S. Sub Depot, Larrycormick, Northern Ireland. (Sale at Belfast.)	OSBORNE KING & MEGRAN (Dept. L), 14, Montgomery Street, Belfast. (Tel.: 27613.)

Acme Gridley bar Automatics 1⅛in. and 2¼in.—6 spindle and chucking Automatics 6in.—4 spindle, Conomatic 1¼in.—6 spindle Automatics, Churchill Redman Conomatic 6 spindle, B.S.A. Multi Tool Geared 6in. by 20in., Drummond maxicut, Ward Capstan, Smart & Brown and other lathes, Cincinnati No. 2 centreless grinders, Jones G.P. milling machines, British Furnaces rotary and tempering and Alldays & Onions porthole furnaces, Ballard conveyor ovens, conveyors and cooling units, Wright swarf breakers, Ingersoll Rand compressor, etc.

October 22	Vehicles	61 B.V.D., Georgetown, and 62 B.V.D., Irvine. (Sale at Glasgow.)	DIXON & WALLACE, LTD. (Dept. L), Bank Buildings, Graham Sq., Glasgow, E.1. (Tel.: Bridgeton 2447.)
October 23–24	Machine tools and miscellaneous stores	Technical Stores Depot, Old Dalby, Melton Mowbray, Leicestershire. (Sale at Melton Mowbray.)	SHOULDER & SON (Dept. L), 1, Norman Street, Melton Mowbray, Leicestershire. (Tel.: 81.)
November 1	Miscellaneous stores	Returned Stores Depot, Reed Hall, Colchester, Essex	FENN, WRIGHT & CO. (Dept. L), 146, High Street, Colchester, Essex. (Tel.: 3171.)
November 6	Miscellaneous stores, including scrap canvas furniture and M.T. spares	Northern Command Ordnance Sub-Depot, Barlow, Nr. Selby, Yorkshire	BARTLE & SON (Dept. L), 50–52, Merrion St., Leeds, 2. (Tel.: 2–0898.)

CATALOGUES (6d. each—P.O.'s) available *only* from the Auctioneers shown above. E975

THE ENGINEER

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THE FIRST ARTIFICIAL SATELLITE

There is no question about it! The Russians have sprung a very exciting surprise on the West. It had long been known that they were preparing to establish at least one earth satellite as part of their contribution to the Geophysical Year; and it had been reported that this satellite would be established on a polar orbit. But because the Americans, believed to be at least as well advanced in rocket technology, did not plan to establish a satellite before next year, the announcement late last Friday from Moscow that a Russian satellite was already circling the earth took everyone by surprise. Even more surprising are certain facts about the satellite. It is reported to weigh about 184 lb, as compared with a mere 20 lb for the projected American satellite (though some commentators seem suspicious that a decimal point has been misplaced!); and it has been established in an orbit stated to be more than 500 miles above the surface of the earth as compared with the American aim to reach a mean height of about 300 miles. Congratulations are unquestionably due to Russian scientists and engineers. A major scientific and engineering feat has been performed. Its magnitude can be well appreciated when it is realised that the American project is marginal; that is, the three-stage rocket which will lift and accelerate a "payload" of only 20 lb into an orbit 300 miles above the earth's surface will have only just sufficient power to establish an orbit from which under the drag of residual atmospheric pressure the satellite would not very rapidly descend. Even so, in order to reach the required velocity the three-stage rocket will project the satellite in an easterly direction so that the rotational surface speed of the earth will contribute to the final speed attained. By contrast the much heavier Russian satellite (supposing it to be confirmed that it does weigh 184 lb) has been established in a more or less polar orbit (65 deg. to the equatorial plane), lacking much of that assistance. If reports about it are true, there is, in fact, much less that is marginal about the Russian achievement. There was more power to spare than the Americans are planning to provide.

To engineers, capable of appreciating the complexity of the technical problems that have been solved, all else pales into insignificance against the achievement of setting up the satellite at all. Further information about the satellite itself, reported to be 23in in diameter, and about the rocket, presumably three-stage, which established it in its orbit will be eagerly awaited. There are already reports that the burnt-out last stage rocket has been detected orbiting around the earth. The discarded nose cone of the rocket should also be orbiting about the earth. But for scientists there are elements of disappointment. The scientific equipment carried by the satellite is rudimentary. It consists apparently solely of two radio transmitters whose frequencies are 20 and 40 megacycles, as compared with the 108 megacycles which had been agreed upon by both Americans and Russians in connection with the International Geophysical Year. There are contradictory reports as to whether the satellite is capable of transmitting information about its own or the surrounding temperature or, indeed, any scientific information at all. Furthermore, the satellite has been established in its orbit so many months earlier than anyone in the West had expected that much equipment on the ground (for example, the Jodrell Bank station—to Professor Lovell's deep disappointment) is not ready to go into action. It is even suggested that the satellite has been established at too high a level in that resistance to its movement from a residual atmosphere at its height will be so slight that it may be many years before it descends to lower altitudes and provides in that way information about the distribution of atmospheric pressure around the earth. Alternative estimates that the useful life will not exceed a few weeks or days illustrate the lack of precise knowledge about atmospheric density at great heights and some present uncertainty about the mean height and eccentricity of the orbit. The present perihelion is stated to be in the Northern hemisphere. But this sense of disappointment is surely unjustified. If the Russians can establish a satellite weighing 184 lb in a polar orbit some 500 miles above the earth it is obviously practicable for them to establish a more fully instrumented satellite in any preferred orbit up to (and possibly beyond) that height. There is no doubt that the Russians plan to do so. It is to be hoped, however, that the world will be informed, next time, well beforehand so that scientific stations the world over will be prepared. This will be all the more necessary should the useful life of satellites established in orbits at 300 to 500 miles above the earth's surface prove to be short. As we go to press, there are already unconfirmed reports that the satellite is losing height. It is understandable that Russian scientists and engineers should have wished to be sure of the success of the first experiment before making an announcement about it. The rulers of the U.S.S.R. relish a spectacular failure even less than Western Governments! But secrecy about a second firing would seriously diminish the scientific value of the experiment.

It has now been made obvious that Russian engineers are ahead of their American counterparts in the design of rockets. There is, indeed, menacing evidence in the setting up of the satellite

that the Russian claim to have developed a successful inter-continental ballistic missile is true. It may well be, indeed, that elements of international politics have entered into the timing of the firing of this first satellite rocket. The paucity of equipment within the satellite lends support to that idea. For surely if suitably designed instruments for making a variety of scientific measurements had been available the opportunity would have been taken to install them. There is then at least a suggestion that suitable instruments have not yet been fully developed in Russia. Alternatively, of course, the Russians may be planning to establish a number of satellites each instrumentally equipped to serve only one or no more than very few scientific purposes. It may be, however, that in the field of instrumentation the Americans are as well ahead of the Russians as the Russians seem to be ahead of the Americans in rocket technology. If so, how unfortunate it is that it is almost impossible to conceive of American instruments being installed in a Russian-fired satellite! For surely in advancing into outer space the nations should act in unity rather than in a spirit of hostile competition.

AGRICULTURAL (AND OTHER) MACHINERY EXHIBITIONS

The spectacular progress of mechanised farming in the post-war years has created a number of problems for that large section of the engineering industry represented by tractor and agricultural machinery manufacturers. One of these problems relates to exhibitions of farming machinery. It is a matter which causes considerable concern, for manufacturers are understandably anxious to have the best possible facilities for displaying and demonstrating their products to potential home and overseas purchasers. There are at present in this country two exhibitions annually, the greater portion of which is regularly taken up by tractors and agricultural machinery and equipment of all kinds. They are the Royal Show, in July, which is an itinerant event, and the Smithfield Show, in December, which is held at Earls Court, in London. Both these shows are now in their second century, both continue to fulfil a useful function, but both retain much of the atmosphere of those times when horses, cattle and other livestock had a far more prominent place in British farming than they do now relative to machinery.

Stock raising is still an important constituent of this country's agriculture. But it is not irrational to claim that, nowadays, next to the land itself, the farmer's machinery and implements are of the higher importance. Furthermore, agricultural machinery produced by British manufacturers in all its great diversity is one of this country's increasingly valuable exports. Prior to the war, not more than about £1,000,000 worth of agricultural machinery made in this country was sold overseas; now, the export value exceeds £66,000,000 a year. It is not surprising, therefore, that at the Royal Show and at the Smithfield Show the machinery stands normally occupy about two-thirds of the exhibition space. The manufacturers are concerned because they feel by no means confident that the various sites for the Royal Show and the customarily crowded conditions of the Smithfield Show really afford the best facilities for an effective and commercially useful display of such a large quantity of engineering products. Agricultural machinery makers have been talking about this matter for many months. Recently, the subject was given fresh impetus, for it was the principal theme of the discussions at the annual conference of the Agricultural Engineers Association. At that conference the need was stressed for the establishment of a permanent show ground in the vicinity of London, a ground which could be used also for exhibitions other than those of agricultural machinery. Among the reasons advanced in support of the proposal was the necessity to provide adequate accommodation and means of entertainment for overseas visitors.

The idea of a permanent exhibition site in this country is not a new one. Other sections of the engineering industry have also often thought about it. But the proposals for a European Common Market and for an eventual European Free Trade Area surely make it more important than ever that some new consideration should now be given to the matter. Engineers who visit exhibitions abroad are among those who realise that much might be gained if this country had a site and buildings which could conveniently accommodate displays of the heaviest machinery and plant. Perhaps the Agricultural Engineers Association has touched off again a suggestion that will readily command the support of other parts of the engineering industry. The question that inevitably arises first, of course, is "Where could a permanent exhibition site be established?" That question has been asked time and again for more than a century! We would not presume to postulate a final answer, confident though we are that this country could provide within its borders an eminently suitable "shop window" for its excellent engineering manufactures. Whatever faults it may have, London is still the greatest city in the world and it is the heart of the British Commonwealth. A well-planned and æsthetically pleasing exhibition site within it is not an impossibility. Would it *really* be disadvantageous if, say, the east side of Hyde Park was transformed to provide such a site?

TRAINING ENGINEERS FOR THE STEEL INDUSTRY

As initially conceived, courses at colleges of advanced technology for the new Diploma in Technology were to be of the same standard as those for a degree, but of differing content. Since then, however, there has been a tendency in some quarters to suggest that in practical fact the difference in content will turn out to be small. In our view it will be unfortunate if there is no significant difference, as in those circumstances either the Dip. Tech. will never acquire a prestige as high as that attached to a degree, or, if it does, there will be introduced an undesirable sense of competition between universities awarding the degree and advanced technological colleges awarding the Dip. Tech. A university degree should be distinctive. No other award should compete with it. Our fears upon this point have recently been somewhat relieved by the setting up at Loughborough College of a course which does turn out to be significantly different in content from those leading to degrees and for which, very fittingly in our view, recognition for the award of the Dip. Tech. is being sought. It is a sand-

The Engineer
100 Years Ago
(OCTOBER 9, 1857)

"HIGH OR LOW PRESSURE STEAM"

"A discussion recently took place at Peel's Arms Inn, Manchester, between Mr. Robert Davies, of Blackburn, and Mr. Edward Ingham, of Oldham, members of the Operative Engineers' Association of Lancashire, Yorkshire, and Cheshire, under whose auspices the meeting was called by printed circular. The room was crowded. The subject of discussion was 'Whether will 35 lb pressure per square inch or 1,000 lb pressure work the cheaper?' . . .

"Mr. Edward Ingham made a few preliminary observations as to how this discussion had originated, and what were its objects; and also as to what were the character and tendencies of the Engineers' Association generally. He then said that even his short experience with high pressure steam convinced him that there was no comparison, in point of economy, between high and low pressure steam. He then read a tabulated statement of the coals consumed at the firm he superintended for the last three or four years, from which it appears that, by raising their pressure only from 26 lb to 50 lb, whilst, in 1854, with 132 indicated horses' power, they consumed 1500 tons of coal; in 1856, with 200 indicated horses' power, they only consumed 1200 tons. . . .

"Mr. Davies said he was only a plain working man, searching after truth on this important subject, and if it could be satisfactorily shown to him that he was in error in the views he entertained, he should go back to Blackburn with feelings of pleasure. He was not alone in his views. In Mr. Longridge's reports he found that the most economical engines were not the compound, using high steam, but the single cylinder engines, using from 20 lb to 2 lb; and Mr. Fairbairn himself, the other day, stated that about 30 lb per square inch was the most economical pressure. Mr. Davies then traced the history of steam from the time of Hero of Alexandria, 130 years before the Christian Era, down to 1781 and 1804, when Hornblower and Woolf introduced the first compound or double cylinder engines; thence to 1811, when a number of the proprietors of Cornish engines established a system of inspection to report the duty of their engines. . . . A miscellaneous discussion then ensued."

wich course in engineering, particularly adapted to train engineers for the steel and other heavy metallurgical industries. Because the problems a steel works engineer has to face are very varied and touch upon a whole range of allied technologies the programme of this engineering course is significantly different from that supplied by a university. The steel works engineer needs, in addition to a sound background of mechanical engineering, a more than usually thorough knowledge of such subjects as industrial metallurgy, heat transfer, lubrication, soil mechanics, electro-mechanics, welded structures and refractories. Additionally, he needs to know something about instrumentation and to be capable of applying some of the methods of operational research. The course is also designed to give the student some appreciation of the various subjects coming under the heading of industrial relationships. The course extends over four years and the first students will enrol next January.

The course, interesting in itself as indicating that the award of a Dip. Tech. can be made to have a meaning different from that of the award of the degree, is notable upon other grounds. Educational courses are usually devised by educational bodies to meet a need supposed to exist within industry. Alternatively, industrial firms, or occasionally groups of firms, may suggest to a university or college the desirability of starting a particular course. The history of the initiation of the course under discussion was different. The course was conceived within the iron and steel industry as a whole. The Training Committee of the British Iron and Steel Federation came to the conclusion that some special course leading to the award of the Dip. Tech. was needed, and after consultation with a variety of interested people within the industry it formulated outline proposals of its own for the course. The next step was to visit a number of colleges with the object of choosing one particularly well adapted academically, geographically and in its equipment and reputation to undertake the provision of a course whose nature was already quite firmly formulated even if only in outline. As we have already remarked, the choice fell upon the Loughborough College of Technology. The industry is to assist the College by providing lecturers on special subjects and it intends to establish close links between the College and engineering services within the industry. We cannot help feeling that there are other industries which might do well to follow a similar practice. If they do, not only will the hopes of those who devised the new award of Dip. Tech. be well on the road to fulfilment, but also that award will have, undoubtedly, a meaning distinctively different from that of a degree, yet it should be able to acquire a prestige no less high.

A Seven Day Journal

Institution of Production Engineers

THE Right Hon. the Earl of Halsbury, president of the Institution of Production Engineers, received guests and took the chair at the Institution's annual dinner in the Dorchester Hotel, London, on Friday, October 4. Proposing "The Guests," the Earl quoted a number of economic statistics deftly enough to improve rather than impair the conviviality of the evening—though he ended on a note of regret that the wages paid for the output of consumer goods had been exceeding those paid for the output of certain capital goods. The guest of honour, Sir John Maud, Secretary to the Ministry of Power, responded to the toast with an entertaining speech, in which he traced the lineage of the production engineer to his evolutionary ancestor, the triceratops (a dinosaur that flourished only in North America). This creature had three horns, said Sir John, so symbolising the abilities of the production engineer. These abilities, he went on, were those of the technologist, the economist, and the manager of men. Sir John invited sympathy for the unfortunate bureaucrat, whose aims and methods, he thought, were very similar to those of the production engineer.

Ince Power Station

THE Right Hon. Lord Citrine, chairman of the Central Electricity Authority, opened Ince Power Station (North West, Merseyside and North Wales Division) last Wednesday, October 9. This station, the first under the Authority to have a semi-outdoor boiler installation, has a total capacity of 240MW from its four 60MW turbo-alternators. Ince is one of the sixteen power stations that it was decided at national level to adapt for oil firing. Built at a cost of approximately £13,500,000, the station was originally projected because it was apparent by the end of 1949 that the demand from the atomic factory at Capenhurst made it essential. The site consists of about 83 acres of an "island" in what was formerly marshland, and the plan of the station has a rather unusual outline in order to interfere as little as possible with agricultural development. The details of the station have excited more than ordinary advance interest, and we hope to publish a fuller account in the near future.

Opening of Two Sewage Purification Works

THE Minister of Housing and Local Government, Mr. Henry Brooke, has recently opened two new sewage purification works in the London area. On October 2 he inaugurated the first stage of the East Middlesex main drainage undertaking, at Deephams Works, Edmonton. The scheme has been in progress for a number of years, and from time to time we have noted in these columns constructional progress at Deephams Works. Eventually, a population of 800,000 and an area of 95 square miles will be served by the works, the ultimate dry weather flow being 32 m.g.d. Extensive trunk sewer construction is involved in the scheme. At present only a limited capacity is available at the works. The storm water tanks and primary sludge digestion tanks are built, and two aeration tanks (ultimately seven or eight) and eight final tanks (ultimately twenty-four or thirty-two) are completed. The consultants are Messrs. J. D. and D. M. Watson.

On Monday the Minister opened the new works of the Hogsmill Valley Joint Sewerage Board. This works is a good example of modern practice in sewage treatment, and will purify sewage from about a quarter of a million people in Kingston, Epsom, Ewell, Malden and Coombe, and Surbiton. As now in operation it has a capacity of 7¼ m.g.d. dry weather flow, and will ultimately cope with 11 m.g.d. The additional flow will be taken over at the Hogsmill Works when two old works, now operating within their original design capacity, are eventually abandoned. The peak discharge which can be pumped into the new works from the sewer system serving it will be 66 m.g.d. The cost of Hogsmill works has been £1,250,000, and of the whole scheme about £2,200,000. The consulting engineers are John Taylor and Sons.

Present Status of Steam

ON Tuesday, October 8, Professor J. Small, D.Sc., Ph.D., delivered his presidential address, entitled "The Present Status of Steam," to the Institution of Engineers and Shipbuilders in Scotland. In the course of his remarks he recalled the early engines of Newcomen and Watt, in which boiler pressure was not an important factor, and the realisation of the effect of pressure with the advent of Trevithick's engine. Then, as now, he continued, metals limited advancement, as did also the lack of knowledge of the thermal properties of steam. Once the science of thermodynamics was established steady advances were made until a point was reached where the law of diminishing returns applied to the advancement of pressure and temperature. However, Dr. Small said regenerative feed heating and reheat cycles had made higher efficiencies possible, although present practice had gone beyond the range of accurate knowledge. Present-day costs made even a gain of a fraction of 1 per cent worth while and a 1 per cent improvement was quoted as representing a capital saving of £70,000 in a power station of moderate capacity.

Professor Small said that pressures had risen from 70 lb to 2000 lb per square inch in the last 100 years; he gave steam conditions for power stations as 600 lb per square inch and 850 deg. Fah. in 1930 and 1500 lb per square inch and 1000 deg. Fah. with reheat to 1000 deg. Fah. in recent years. Figures for supercritical units in America were given as 5000 lb per square inch and 1150 deg. Fah., and the president went on to mention "creep" properties of metals and their composition as related to temperature, and weldability. Present developments, he claimed, had outstripped known data of the chemistry of feed water and of the effects of feed water treatment on steam generation so that fundamental research was called for. In the United States, Dr. Small continued, work was proceeding, with the formulation of thermodynamic properties, on thermal conductivity and viscosity, and on the property of viscosity. In this country Professor Newitt, at the Imperial College, was engaged on carrying the range of values of the thermodynamic properties up to a pressure of 1000 atmospheres and 750 deg. Cent., while at the University of Glasgow the original programme of measurements of viscosity and thermal conductivity up to 10,000 lb per square inch and 750 deg. Cent. had been modified and present research was concentrated on the viscosity.

Radio Valve Industry

In his inaugural address as president of the Institution of Electrical Engineers in London on October 3, Mr. T. E. Goldup surveyed the radio valve industry in retrospect and prospect. The major part of the address, abstracts from which are reproduced here, was concerned with new developments, including microwave valves, semi-conductors and low-temperature devices, and their application.

CHANGE has been the essence of valve development from the time of Fleming's early work, and as our knowledge of electron emission, vacuum techniques, circuits, and so forth, has expanded, so has the thermionic valve become increasingly a device of almost limitless scope opening up an ever-widening horizon of application possibilities.

I will first refer to microwave valves, special quality valves and semi-conductors.

Microwave Valves

In microwave valve development, a requirement of some importance is the availability of cathodes having extremely high emission current densities, and a good deal of work has been directed towards the solution of this problem. As a result, some novel forms of cathode have appeared, one example being the dispenser type pioneered by Lemmens, where the emissive materials percolate to the surface of a porous tungsten body when the cathode is heated. This development has materially assisted the progress of microwave valve design towards meeting the ever-increasing demands for higher frequencies and powers.

Magnetron developments derived great impetus from military requirements for high pulse powers in radar systems. Initially conceived in this country by Randall, Boot and Sayers at Birmingham University, this device was rapidy taken up by America and became the subject of intense study. The main application for magnetrons is still in pulse radar and to a large extent will remain so, although some types of radar are likely to forsake the magnetron for devices such as the klystron or the travelling-wave tube.

In recent years the magnetron has made possible many new advances in conventional radar systems. The success of the British marine radar manufacturers in supplying the major part of the world's demand is well known, and becoming more common is civil aircraft airborne radar for cloud and collision warning sets. The availability of magnetrons operating on wavelengths of a few millimetres has made feasible the radar control of ground movements on airport runways. Although radar using the pulse magnetron is considered to be rather old-fashioned, there is still a great deal of scope for expansion ; in particular, one would expect to see magnetrons developed for still shorter wavelengths to provide greater resolving power for radar sets in cases where range is not important.

Apart from radar applications the magnetron has been extensively used as a source of radio-frequency power for linear accelerators. These instruments, in which electrons are accelerated to high energies, were initially developed as an atomic energy research tool and were then used for medical, radiotherapy, and X-ray purposes. They now fulfil an important application in industrial processes connected with plastics. An example of this is the irradiation of polyethylene to increase its heat-resisting properties. The electrical industry is indeed indebted to the plastics industry for some of the modern advances in insulating materials, and the use of linear accelerators is, as it were, something given in return.

A limited application for magnetrons is as a source of power for radio-frequency cookers, and we may well see this gaining favour in the future. Food either precooked or raw is placed in the " oven " and subjected to strong microwave radiation, so being heated or cooked extremely rapidly by dielectric loss. The cost involved, however, may for the moment exclude its domestic use, but large caterers may favour the idea and use such a system.

The klystron was developed in its reflex form as a local oscillator for superheterodyne receivers, and although the original ideas were American, a great deal of work was initiated in this country during the war, the contribution of Sutton and his team at Bristol and the effort at the Clarendon Laboratory being well known. Of late many improvements have been made in reflex klystrons in regard to ruggedness, reliability, life, and use at higher frequencies. Types have already evolved operating at wavelengths of 2mm or 3mm.

In the past the amplifier klystron received little attention because the magnetron produced radio-frequency powers with greater electronic efficiency and in return for far less development effort. Now, however, the situation is changing with the introduction of phase-coherent radar, where the reflected pulse from a target is compared in phase with that which was transmitted, the resulting beat frequency being a measure of the target velocity. A fixed object will produce a zero beat in a phase-coherent system, and this identifying feature enables permanent echoes to be eliminated from the display screen. In addition, one can measure with great accuracy and instantaneously the velocity of a target—a point of considerable interest in any navigational problem, military or civilian.

There are many different variants of the phase-coherent radar system, an important common factor being the need for improved microwave amplifying valves, with the result that in this field work is being directed towards larger powers, higher efficiencies and increased bandwidths. Pulse powers of the order of megawatts are now possible and, in the lower power types, gains in excess of 100 dB have been achieved. But by no means are all the answers known. Active research continues in the field of multi-cavity klystrons, where the problems are largely fundamental, involving the formation and maintenance of electron beams of very high current density. In slightly different applications the amplifier klystron has recently come into extensive use in navigational aids and in television broadcasting in bands IV and V.

The travelling-wave tube was a most significant wartime invention, first conceived by Kompfner while working for the Admiralty. Kompfner's work showed that when a wave was travelling slowly along a structure such as a helix, a beam of electrons travelling at almost the same velocity and in close proximity to the wave would interact with and amplify it, the extra energy in the amplified wave being derived from the kinetic energy of the electrons which are slowed down in the process. An important feature of the travelling-wave tube is the fact that, by special treatment of the electron beam after it leaves the cathode, the noise due to random velocity and density of the electrons can be largely removed, thus giving tubes with low noise factors which are particularly suitable for use as signal amplifiers.

The travelling-wave tube has received concentrated attention during the post-war years because the high gains and broad bandwidths obtainable make it ideally suited for use in centimetric wavebands for radio relays. The use of these wavebands has been necessitated by the big increase in the volume of traffic in telegraphy, telephony and television; for instance, the last named utilises a bandwidth which could accommodate 1000 telephone conversations. The world's first radio relay using a travelling-wave tube was set up by the Post Office early in 1952 between Manchester and Kirk o'Shotts, since when complete ranges of tubes are becoming available for use in the programme for radio relays mentioned by Sir Gordon Radley in his Presidential Address of 1956.

Travelling-wave tubes are not necessarily limited to the few watts of power required in communication. Studies at really high power levels are progressing, and it may be that these tubes will become serious competitors of the amplifier klystron, for they are less complicated in many respects, having no tuned cavities and a simple magnetic focusing system. I believe that, in the long term, some communication will be carried out by the propagation of millimetric wavelengths along small-diameter waveguides. The possibility has already been demonstrated over fairly long distances, but many details remain to be worked out in connection with the actual propagation. In the meantime the valve industry realises that the successful development of such a scheme is dependent upon the provision of practical oscillator and amplifier tubes, on which work is already proceeding, together with the more difficult and fascinating problem of miniaturisation.

Backward-wave oscillators and amplifiers are particular forms of travelling-wave tubes having the advantage that they can be tuned by merely changing the anode voltage. It is difficult to see what the application of backward-wave oscillators will be, but apart from certain military possibilities one can imagine them eventually replacing the klystron as a local oscillator.

The [forthcoming] International Convention on Microwave Valves will be of considerable importance in placing on record the huge volume of work that has been achieved in this field, not only here but in other countries. The gap in the spectrum between electromagnetic waves and infra-red radiation is closing, and how far this is so may be revealed in some of the papers to be presented.

Special-Quality Valves

During the period between the two world wars the urge for improvements in valve quality, performance and reliability resulted largely from the demands of the broadcast receiver manufacturers, and fruitful collaboration between them and the valve designers determined to quite a considerable extent the direction and scope of valve development. As a result, with the arrival of different applications, such as communication and airborne radar, the valves incorporated in them initially were those based

on the design requirements of the domestic market. Such valves, however, were not primarily intended to withstand the shock and vibration associated with these new applications, so that there arose a need for a series of valves whose characteristics would not be impaired, nor their life shortened, by these more arduous conditions. The valve manufacturers, with the support of C.V.D., set to work to design valves to meet these new requirements, and found it necessary to study the properties of materials, the fatigue behaviour of glass, metal and mica, the influence of static stresses within the valve, the effect of cyclic stresses applied externally, the causes of gradual deterioration of electrical properties of the valve, and finally to review critically existing manufacturing methods. All this, and the development of sub-miniature types for missile work, has added greatly to our general knowledge of valve manufacturing technology, the result being that several types of special-quality valves are now available, produced in air-conditioned plants under conditions similar to those obtaining in the manufacture of pharmaceutical products.

Semi-Conductors

The transistor was invented in 1948 at the Bell Telephone Laboratories in America during a study of the effect of external fields on the conductivity of semi-conductors. The first transistor was a point-contact type, but theoretical considerations soon showed that the principles could lead to a sturdier device—the junction transistor. The first prototype of this kind was made in 1951.

Because the transistor is an amplifying device, it has a very wide range of applications in the electronics field. It is extremely small and requires very little power to operate it ; for these reasons it is destined to have a profound influence on the design, for example, of computers, of Post Office equipment such as repeaters and exchanges, and of Service equipments of every kind for use on land, sea and in the air. For the reasons already mentioned, the transistor will also greatly modify the design of components.

One of the main lines of transistor development, both here and elsewhere, is towards types which can operate at the higher frequencies. In America types operating up to 10 Mc/s and over are already in production ; the theoretical limit, speaking from our present knowledge, seems to be in the region of 1000 Mc/s or, at the most, a few thousand megacycles per second.

Another semi-conductor device with an important future is based on the fact that, when charge carriers are injected into a junction, multiplication occurs, rather like electron multiplication in an ionised gas. This effect can be used to produce very-high-frequency oscillations, and from the theoretical point of view perhaps eventually even in the region of centimetric waves.

The change between two possible energy states in molecules can be used for microwave oscillation or amplification, the interaction between a microwave system and a substance falling from a higher to a lower energy state enabling power to be extracted. One class of amplifier of this kind uses semi-conductors and provides *m*icrowave *a*mplification by *s*timulated *e*lectromagnetic *r*adiation, from which is derived its abbreviated name Maser. This device can operate only at low power levels, and theoretically its efficiency and bandwidth are not great. But useful gain can be obtained, and at the extremely low temperature at which it must be operated its signal/noise ratio is extremely high.

The ideas using solid materials for electronic devices, which I have outlined, are still so new that their importance and the extent to which they will be developed cannot be foreseen at present. It is possible, however, that they may provide the key to the whole field of millimetric waves.

Not the least important aspect of the great developments in this field is the enormous stimulus that has been given to research into the physics of solids. This field is growing in both volume and importance, and because of this we can undoubtedly expect this new science and technology to produce many novel and probably revolutionary devices and applications within the next few years.

Automation

Automation is no new thing and has been introduced in varying degrees into many industries ever since the industrial revolution. The reason, I believe, why so much attention has been focused on it in recent years is that, whereas formerly we made machines which could assist our physical efforts, we are now, largely through the application of electronics, able to make machines which can augment our mental efforts. We can give machines " electronic eyes and ears," to use the Duke of Edinburgh's expressive phrase, and these sensing elements can feed back the information they receive so that any departure from the required result can be corrected. In addition it is now possible to give a machine a programme which instructs it to perform certain operations or to react in certain ways. In complicated systems these relatively new elements—feedback and programming—lead to the use of computers and electronic memories.

It is, in my view, the social rather than the technical implications of automation which have attracted most attention. Probably no other recent advance has had so many words poured out on it and has been so misunderstood. From what one reads and hears one could well imagine that it is only a matter of time before all our thinking and manual work will be carried out by machines. This is very far from the truth, and I feel it would be appropriate for me to attempt to put this new development into some perspective.

Within a volume the size of our heads we each have a brain weighing some 3 lb and consisting, I am told, of some 10,000 million individual cells,* which is about thirteen times the world production of valves in 1956. Among its countless other functions, our brain includes the equivalent of a compatible black-and-white and colour television system, a sound recording and reproducing system, and an ability to recognise complex patterns which outstrips any practical mechanical or electronic equipment. If it were possible to construct a machine able to perform the same functions as the human brain, it would inevitably have to be largely electronic ; if we brought together all the necessary component parts and could then in some miraculous way solve the vast problem of connecting them together, we should still be faced with the fact that, even with the most reliable modern components, several hundred would be faulty at any given instant.

Low-Temperature Devices

In its onward advance, electronics is constantly establishing links with fields which only a few years ago seemed quite remote. In recent years it has reaped much by its association with ferrites and semi-conductors, and now it is once again crossing the boundaries of new territory—this time into the low-temperature field. There are three main reasons why this advance is taking place : first, recent progress in low-temperature techniques has made the creation of temperature near absolute zero a matter of no very great difficulty ; secondly, more complicated and therefore larger equipments costing, say, £100,000 or more, in which low-temperature facilities can economically be provided, are nowadays more frequently considered ; thirdly, because of the extremely low noise level at temperatures near absolute zero, devices which operate in this region hold great attractions for the electronic engineer.

There are two main developments in low temperatures—I have already mentioned the first, the Maser, in dealing with semi-conductors. The second, the Cryotron, is a switching device which consists of a straight wire with a second wire coiled round it, both immersed in liquid helium and therefore having effectively zero electrical resistance. However, the resistance of the straight wire is restored when a sufficiently strong magnetic field is produced by a current in the coiled wire. The current required is only a fraction of that in the straight wire, and the effect can be produced within microseconds ; the device thus acts as a very-high-speed relay. It has the advantage of simplicity and small size, and although it is too early yet to judge its value fully, it may well have wide applications in large computers.

Education and Training

Referring to teachers for technical colleges, the report, " The Supply and Training of Teachers for Technical Colleges," of a special committee under the chairmanship of Dr. Willis Jackson appointed by the Minister of Education in September, 1956, and published a few months ago, sets out very completely the nature and extent of the problem. Of special significance to this Institution and to the whole electrical industry is the statement of future needs, showing that a full-time teaching staff of 11,500 in 1955–56 should be increased to 18,600 in 1960–61, and part-time staff from 39,000 to 47,000 in the same period. Equally significant is the opinion expressed by the committee that educational institutions and industry tend " to regard themselves as separate and distinct rather than as intimately associated partners in a joint enterprise."

In spite of the many difficulties in its application, industry should most carefully consider how to implement the following statement appearing in this report : " Industry . . . must be willing to accept and indeed to encourage and assist the transfer to full-time teaching work of experienced staff it can ill-afford to lose as the only means of ensuring a much augmented supply of suitable recruits of high quality."

The new course for the Diploma in Technology is only one of many factors which are increasing the demands for practical training, the burden of which is carried almost exclusively by the larger industrial concerns. There is a limit to what these organisations can do, however, and even though this limit has perhaps not yet been reached, it is clearly right and necessary that smaller firms should contribute their share to the pool of practical training facilities. A very few such firms are already contributing through co-operative training schemes, and they have shown that, given the right conditions, such schemes can be successful. Because extra men will be available owing to the bulge going through the secondary schools, and because of the tail-off in call-up, there is an urgent short-term need to provide additional practical

* Bowden, B.V.: " Faster than Thought."

training facilities, quite apart from the long-term implications of the position. It would be a disastrous paradox if, at the time when schools, colleges and universities are increasing their outputs in an attempt to provide the additional men which industry has called for over such a long period, industry itself should fail to have available the practical facilities without which training cannot be properly completed.

We must all welcome the Government decision for a progressive decrease in the numbers called up for National Service, which is thus likely to end in 1960; in addition, it is probable that in 1958 and 1959 not all those liable for Service will actually be called up. However, in these two years all trained men who have been deferred will continue to be called up even if more are available than the Forces require to meet their needs for skilled manpower. Obviously, industry could well do with this surplus. This waste of our most valuable commodity—trained personnel—is very disturbing, and one must hope that the policy behind it will be further considered.

Theory of Shaft Whirling

A FUNDAMENTAL APPROACH TO SHAFT WHIRLING

By E. DOWNHAM, B.Sc. (Eng.), Ph.D., A.F.R.Ae.S.*

No. I

The introduction in modern aircraft of complex engine-propeller installations, and of axial-flow compressor turbines with high rotational speeds and intricate construction, has brought the old problem of shaft whirling once again into prominence. Not only has it become necessary to estimate critical speeds of individual power plants with accuracy, but regard has to be paid to the flexibility of the mounting structure and the effect that even momentary and incipient whirls may have on an aircraft structure. In this paper, an attempt has been made to show the pitfalls made by early writers on the subject, and to establish clearly the basic theory on the lines indicated by Jeffcott. An experimental approach is then described, and results presented, which, combined with the theoretical approach, provide a firm foundation for a study of the more complex whirling problems.

SINCE as far back as 1869 when Rankine published one of the first papers on shaft whirling[1] in THE ENGINEER, attempts have been made to establish accurate methods for the estimation of critical whirling speeds of complex systems. Many of the theories propounded have since been shown to be based on fallacious arguments, and it was not until 1919, when Jeffcott's paper[5] was published, that the exact dynamics of shaft whirling were clarified. Despite the work of Jeffcott, however, even to-day many textbooks still quote the early works based on incorrect appreciations of the nature of shaft whirling. A valuable contribution to the theoretical work in recent years has been made by Morris,[10, 11] who extended the early Jeffcott theory to include the more complex aircraft-engine-propeller systems with contra-rotating propellers and asymmetric inertia and stiffness.

Examination of the long history of the study of shaft whirling shows that although there has been much effort given to solving the many whirling problems theoretically, the experimental approach has been, by modern standards, neglected. In particular, full advantage has not been taken of modern electronic and photographic techniques. The result is that many different theoretical methods are at present in use for calculating critical whirling speeds, which have never been confirmed experimentally and which take little account of the constraints peculiar to specific installations.

HISTORICAL REVIEW

On April 9, 1869, an article was published in THE ENGINEER "On the Centrifugal Force of Rotating Shafts," by W. J. M. Rankine.[1] The object of this communication was "... to explain in a form suitable for practical application, the results of a mathematical investigation of the action of the centrifugal force in long lines of shafting; an action of which no similar investigation has, to my knowledge, been hitherto published; although it is one which may seriously affect the strength, durability and economical working of machinery." This was the first, but by no means the last, publication related to the problems of shaft whirling.

There appears to have been a lapse of some fourteen years before the next paper of note was published. This was a paper communicated to the Institution of Mechanical Engineers in April, 1883, by Greenhill,[2] "On the Stability of a Rotating Shaft, subject to Thrust and Twisting; for instance, a Screw Shaft." The work of Greenhill was followed in 1894, eleven years later, by the classic experiments of Dunkerley,[3] which were reported and published in the *Philosophical Transactions of the Royal Society*. In this paper, Dunkerley describes experiments which he had carried out with various arrangements of shafts and pulleys. The results of these experiments were compared with calculations based on a theory propounded by Professor Osborne Reynolds, and an empirical formula was derived for calculating the critical speeds of shafts carrying a number of pulleys. The next important contribution to the subject was made by Chree,[4] in 1904, in a paper published in the *Philosophical Magazine*, Vol. 7, entitled "The Whirling and Transverse Vibrations of Rotating Shafts." In this paper, Chree "... thought it worth while to examine the whole question afresh, from a variety of points of view, making liberal use, however, of Dunkerley's experimental results, and referring to his formulæ in the several cases, so that the present work is in many respects supplementary to his." The above-mentioned papers were mainly concerned with unloaded shafts in which the critical speeds were calculated by the use of the ordinary elastic solid equations applicable to thin rods acted on by "centrifugal force" and was simply the Bernoulli-Eulerian method described in textbooks treating "thin" rods.

In order to cope with the problem of a pulley mounted on a heavy shaft, Dunkerley first calculated the critical speed for the loaded shaft, in which the mass of the shaft itself was neglected, by methods considered by Chree to be analogous to Lord Rayleigh's method for obtaining approximate frequencies of vibration. Calling the frequency thus obtained N_2 and that found for the unloaded shaft by the first method N_1, Dunkerley deduced a final value N for the frequency of the complete system, from the equation

$$\frac{1}{N^2}=\frac{1}{N_1^2}+\frac{1}{N_2^2}$$

which is an empirical expression widely used at present.

There is one fundamental fallacy in all the early work on shaft whirling, which seems to indicate that not one of the authors mentioned appreciated fully the nature of shaft whirl. This fallacy is apparent from the following quotation from Chree's paper (page 508, paragraph 4):—"As stated above, whirling is not really a case of coincidence of period between a vibrating system and disturbing forces. ..." This brief quotation is in complete disagreement with modern concepts of shaft whirling and even at the present time there are published advanced textbooks on mechanics, which follow these completely erroneous concepts, in their treatment of shaft whirling. It is unfortunate that for the simpler cases of shaft whirling (negligible rotor inertia and symmetric stiffness, &c.), the critical whirling speeds occur at the same frequency as the natural vibratory frequency of the system. The assumptions made in the treatises mentioned above all arrive at this conclusion and, hence, the calculated critical whirling speeds are numerically correct. Having arrived at a correct answer to the problem, it was consequently assumed that the theoretical approach was correct. It was therefore fifteen years after Chree's treatise before a rational explanation of shaft whirling appeared. This was in the form of a paper published in the *Philosophical Magazine* (Vol. 37, 1919), by H. H. Jeffcott,[5] entitled "The Lateral Vibration of Loaded Shafts in the Neighbourhood of a Whirling Speed—The Effect of Want of Balance."

The difference between the approaches of Jeffcott and Chree are apparent from the following quotation from Jeffcott's opening chapter, viz: "When a shaft ... is rotated, its geometrical axis ceases to remain straight and in coincidence with the axis of the bearings, but becomes bent and rotates round the latter axis.† The amount of this bending depends on, among other things, the relation of the speed of rotation to that of any of the free lateral vibrations of the shaft. ..." From this basic conception of whirling Jeffcott produced a theory which, for the first time, could be used to explain the behaviour of a simple rotating shaft rotor system at any speeds. Using Jeffcott's basic assumptions it has since been possible to treat any of the more complex systems (systems with asymmetry and contra-rotating shaft systems) with satisfactory conclusions. Unfortunately, many subsequent writers on the subject were either unaware of the significance of Jeffcott's conclusions or chose to ignore them. For many years after 1919 many of the papers published on shaft whirling still followed the old concepts of Dunkerley and Chree, &c.

It is of interest to note that from seven modern text books on Mechanics and Vibration Theory examined by the author, only two were found to mention the work of Jeffcott in connection with shaft whirling. The remaining five based their approach on

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† When the shaft is horizontal, the straight form or axis of the bearings is understood to refer to the gravitationally deflected form.

the work of Dunkerley and Chree. Of these two books, the most important is that written by Captain J. Morris,[10] entitled *The Escalator Method in Engineering Vibration Problems*. In his chapter on the vibration of rotating shafts, Captain Morris has extended the work of Jeffcott to cover more complex systems and it is on this work that the author has based the experimental investigations described later. Whilst this work was being carried out, Captain Morris was attached to the Royal Aircraft Establishment as a consultant in Structures Department. It was possible, therefore, for the author to obtain personal advice from Captain Morris on theoretical aspects of the problem, which proved of great value in the formulation of the experimental approach.

So far the history of shaft whirling theory has been discussed, from which it is apparent that there has been no lack of effort applied to the subject. This is not the case on the experimental side, where there has been relatively little work reported. The most important of the early experiments, as already mentioned, were carried out by Dunkerley, who investigated the critical whirling speeds of loaded and unloaded shafts under various conditions of bearing support. Unfortunately there are fallacies in Dunkerley's theoretical approach, especially when he attempted to account for the effect of rotor inertia. His initial attempts to arrive at a solution to this problem met with little success when the effect of the mass of the shaft had to be accounted for. Ignoring the mass of the shaft, he evolved a solution which again led him to erroneous conclusions. For the simple case of the cantilever shaft he predicted two critical speeds. A lower or "inferior" speed at which the effect of the inertia of the rotor was zero and a higher or "superior" speed at which the effect was infinite, the latter speed being twice the former. He concluded with the statement that "..., the period of whirling, corresponding to the inferior limit of speed, is identical with the natural period of vibration of the light shaft ..." whereas it is now well known an increase of the rotor inertia will cause a decrease in the natural frequency of the system and an increase in the critical whirling speed. Dunkerley's experiments were carried out with rotors of relatively small inertia and the effect of this inertia was inside the limits of experimental error. He was therefore unable to check this part of his theory.

It would be wrong to say that Dunkerley's work was wasted as his empirical formula

$$\left(\frac{1}{N^2}=\frac{1}{N_1^2}+\frac{1}{N_2^2}+\ldots\right)$$

for the critical whirling speed of a shaft system with many loads is widely used at the present time and can be shown to give a close approximation even when applied in the limiting case of a uniformly loaded shaft (i.e. a light shaft with an infinite number of loads).

Stodola[6] carried out more extensive experiments, and although his theoretical work appears to be based largely on the work of Dunkerley and Chree, some of these experiments are very interesting. By means of simple experiments he demonstrated how the c.g. of a rotor moves from a position outside to one in between the shaft centre and the geometric centre, as the critical speed is passed. He also carried out similar experiments to those of Dunkerley on the critical speeds of unloaded and of loaded shafts but the agreement between theory and experiment was not very good. One of his most interesting experiments was concerned with the influence of the viscosity of the surrounding medium on the critical speed of an unloaded shaft. For this a shaft 0·276in diameter and 94·5in long was run in a long trough of water and then in air. The results gave little difference in the critical speeds of the shaft but a most pronounced reduction of amplitude was measured when the shaft was run in water. Stodola also attempted, not very successfully, to investigate the influence of torsional vibration on the whirling of shafts.

Of the more recent authors, Professor Robertson[7, 8, 9] appears to have been the most prolific. He concerned himself mainly with the more academic aspects of shaft whirling, such as skew shafts, hysteretic effects and transient whirling. This work is described in articles published in THE ENGINEER (August 31, and September 7, 1934); also in the *Philosophical Magazine* (S. 7, Vol. 20, No. 135, November, 1935), and in the *Proceedings of the Institution of Mechanical Engineers* (1935, Vol. 131).

Experiments concerned with the "measurement of internal friction in a revolving deflected shaft," including also the effects of shrink fits of rings on hubs have been carried out by A. L. Kimball and D. B. L. Newkirk[12, 13, 14] in America. In more recent years the works of Hagg[15, 16, 17] and Pinkus[18] are of interest, although primarily concerned with secondary whirls associated with oil-film effects.

THE FUNDAMENTAL THEORY OF SHAFT WHIRLING

For simplicity in illustrating the character of forced vibrations on a rotating shaft carrying an eccentric mass, consider the case of a light shaft supported freely in bearings and carrying a mass m whose c.g. is displaced by an amount h from the centre of the shaft. It is assumed that the moment of inertia of the mass is small. Let c be the load required at the rotor to produce unit deflection of the shaft at that point.

The Theoretical Approach of Dunkerley and Chree.—In order to demonstrate the fundamental fallacy in the approach of Dunkerley, Chree, &c., to the problem, let us first consider in more detail their basic approach.

Referring to Fig. 1, it is first postulated

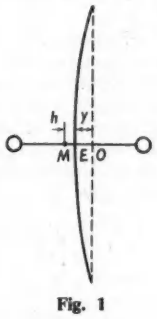

Fig. 1

that for a shaft speed of $\omega<\omega_c$ (the critical speed), the shaft will take up a bent form and whirl about the static axis with radius y, the c.g. having radius $(y+h)$. The centrifugal force $m(y+h)\omega^2$ is then equated to the restoring force cy, giving an equation $m(y+h)\omega^2=cy$

Therefore

$$y=\frac{mh\omega^2}{c-m\omega^2}$$

and when $c=m\omega^2$, $y=\infty$.

Therefore the critical whirling speed is given by:

$$\omega_c^2=\frac{c}{m}$$

When $\omega>\omega_c$, y becomes negative, but the solution gives no indication of the behaviour of the c.g. of the rotor as the shaft speed passes through the critical speed. In fact, the correct value for ω_c is obtained fortuitously because for the simple symmetrical case considered the whirl path is circular, and the solution is of a particular rather than of a general nature. Having established the critical speed to be the same as the natural transverse frequency it is now usual to treat the problem as an ordinary vibration problem and solve by the methods of Rayleigh or the Bernoulli-Eulerian method of treatment for thin rods. These methods give no indication of the fundamental nature of shaft whirling.

The Jeffcott Theory.—Consider now the approach made by Jeffcott. In Fig. 2 O is

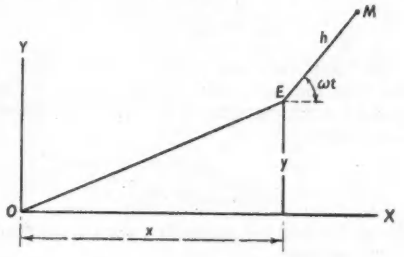

Fig. 2

the static centre of the shaft at the point of attachment between shaft and rotor, E is the displaced centre of the rotating shaft having co-ordinates x and y about the fixed axes OX and OY, respectively, M is the c.g. of the rotor displaced by an amount h from E. It is given that the shaft is rotating with angular velocity ω. This angular velocity determines the angle ωt which the line EM reaches with the horizontal at time t. It is assumed that if the shaft is statically deflected due to the mass m of the rotor, it will initially rotate about its deflected axis and not about the axis of the bearings. This is the fundamental concept of shaft whirling and can easily be verified by placing a straight piece of thin rod in the chuck of a lathe. The rod will droop under its own weight and when rotated will rotate about the bent axis. Furthermore, whilst the rod is rotating, say, at a speed above its critical where the whirl amplitude is small, if the end is struck a sharp blow, the rod will vibrate laterally in the direction of the blow.

On this assumption there will be acting at the point E the following forces:—

(1) A restoring force c times the distance of the elastic centre of the shaft from the axis of the bearings.

(2) A damping force and

(3) A disturbing effect produced by an impressed rotation combined with the fact that the centre of the mass is placed eccentrically with respect to the elastic centre.

The equation of motion of the rotor parallel to OX is therefore

$$m\frac{d^2x}{dt^2}+b\frac{dx}{dt}+cx=mh\omega^2\cos\omega t \quad . \quad . \quad (1)$$

where b is the damping coefficient due to viscous resistance.

The solution to this equation will be

$$x=Ae^{-\frac{bt}{2m}}\sin(qt+\alpha)+\frac{mh\omega^2}{\sqrt{(c-m\omega^2)^2+b^2\omega^2}}\cos(\omega t-\beta) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where

$$\tan\beta=\frac{b\omega}{c-m\omega^2}$$

and

$$q=\frac{\sqrt{4cm-b^2}}{2m}$$

and corresponds to the free vibration period of the shaft. A and α are arbitrary constants.

Similarly, the equation to the motion parallel to OY is

$$m\frac{d^2y}{dt^2}+b\frac{dy}{dt}+cy=mh\omega^2\sin\omega t \quad . \quad . \quad . \quad (3)$$

and the solution is

$$y=A'e^{-\frac{bt}{2m}}\sin(qt+\alpha')+\frac{mh\omega^2}{\sqrt{(c-m\omega^2)^2+b^2\omega^2}}\sin(\omega t-\beta) \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The first term in the solution represents an oscillatory motion of amplitude

$$Ae^{-\frac{bt}{2m}} \text{ or } A'e^{-\frac{bt}{2m}}.$$

This amplitude diminishes with time t so that the term becomes negligible. The second term persists and is a vibration of amplitude.

$$\frac{mh\omega^2}{\sqrt{(c-m\omega^2)^2+b^2\omega^2}}.$$

From (2) and (4), neglecting the exponential term, we have

$$x^2+y^2=\left[\frac{mh\omega^2}{\sqrt{(c-m\omega^2)^2+b^2\omega^2}}\right]^2[\cos^2(\omega t-\beta)+\sin^2(\omega t-\beta)]$$

$$=\left[\frac{mh\omega^2}{\sqrt{(c-m\omega^2)^2+b^2\omega^2}}\right]^2=\text{constant}.$$

The motion is therefore circular round the axis through O and of amplitude

$$\frac{mh\omega^2}{\sqrt{(c-m\omega^2)^2+b^2\omega^2}}.$$

This amplitude is a maximum when

$$\omega_c=\frac{2c}{\sqrt{4mc-2b^2}}$$

or when damping is neglected,

$$\omega_c=\sqrt{\frac{c}{m}}$$

which is the same as the natural transverse frequency of the shaft.

The phase of the displacement of the mass centre relative to that of the elastic centre is given by β, where

$$\tan\beta=\frac{b\omega}{c-m\omega^2}$$

when

$$\omega=0, \quad \beta=0$$

when

$$\omega=\sqrt{\frac{c}{m}}, \quad \beta=\frac{\pi}{2}$$

when

$$\omega\to\infty, \quad \beta\to\pi,$$

i.e. as the shaft passes through its critical speed the centre of gravity of the rotor moves from a position remote from the centre line of the bearings relative to the elastic centre, to a position between the elastic centre and bearing centre. As the damping coefficient b is usually small, this change of phase will take place almost entirely at speeds close to the critical speed. When ω becomes large relative to ω_c, the amplitude of whirl approaches a value h, i.e. the c.g. of the rotor tends to rotate on the static elastic centre of the shaft.

A comparison between these two approaches to the problem shows, that whereas the early writers have assumed a circular whirl, and established a critical speed based on this assumption, by means of a theory which is discontinuous at the critical speed, the Jeffcott approach assumes only that initially the centre of gravity of the rotor rotates about the elastic centre of the shaft. On this assumption the theory proves the motion to be circular and also demonstrates the nature of the whirl on either side of the critical speed. It is also applicable to any shaft-rotor system, symmetric or asymmetric, as, for example, the case of a shaft rotating in bearings having asymmetric flexibilities described below.

Effect of the Weight of the Shaft

Before proceeding to the more complex case, and in order to apply the basic theory to a practical case, it is necessary to consider the effect of the weight of the shaft on the whirling characteristics of a system. Three popular methods are available, which are as follows :—

The Energy Method.—In this method an equivalent system is calculated having the same kinetic energy when vibrating transversely as the shaft-rotor system under consideration. Let v be the transverse velocity at a given instant at the free end of the shaft, and assume that the shape of the curve into which the vibrating shaft deflects is the same as the static deflection curve of a cantilever loaded at one end. At a distance x from the fixed end, the velocity is given by

$$\frac{3lx^2-x^3}{2l^3}.v$$

and the kinetic energy of part δx

$$=\tfrac{1}{2}\frac{w\delta x}{g}\left(\frac{3lx^2-x^3}{2l^3}\right)^2v^2 \quad (w=wt/\text{unit length of shaft}).$$

Therefore

$$\text{K.E. of shaft}=\frac{w}{8gl^6}v^2\int_0^l(3lx^2-x^3)^2dx$$

$$=\frac{33}{280}\frac{wl}{g}v^2.$$

The K.E. of a light shaft loaded at the end

$$=\tfrac{1}{2}\frac{W}{g}v^2.$$

Therefore the equivalent mass of the shaft

$$=\frac{33}{140}\times\text{weight of shaft}=\frac{wl}{4\cdot24}.$$

The Natural Frequency Method.—In this case the natural frequency of the uniformly loaded shaft is calculated, and the mass required on the end of a similar light shaft is calculated to give the same natural frequency. Using the Rayleigh method of equating maximum kinetic energy to maximum strain energy gives an equation

$$\omega^2=\sqrt{\frac{g\int_0^l ydx}{\int_0^l y^2dx}}$$

for the natural frequency of a uniformly loaded beam.

In the case of a cantilever we have

$$y=\frac{w}{24EI}[6l^2x^2-4lx^3+x^4]$$

and

$$\int_0^l ydx=\frac{wl^5}{20EI}$$

$$\int_0^l y^2dx=\frac{104}{45}\times\frac{\omega^2l^9}{576EI}.$$

therefore

$$\frac{1}{\omega^2}=\frac{13}{162}\frac{wl^4}{EIg}.$$

For a light cantilever loaded at the free end we have

$$\frac{1}{\omega^2}=\frac{Wl^3}{3EIg}.$$

Therefore the equivalent weight of the shaft

$$W_e=\frac{13}{162}\times3\times wl$$

$$=\frac{1}{4\cdot15}\times\text{weight of shaft.}$$

The Dunkerley Method.—Another method which is often easier to apply with relatively good results is an extension of the Dunkerley empirical formula for a shaft carrying a number of loads. Dunkerley postulated that if ω_1= the natural frequency of a beam carrying load number 1 with the other loads removed, ω_2=the natural frequency of beam with load number 2 only, &c., then the natural frequency of the system would be given by

$$\frac{1}{\omega^2}=\frac{1}{\omega_1^2}+\frac{1}{\omega_2^2}+\ldots.$$

Applying this to a uniformly loaded beam we have, for a section distance x from the origin, width dx

$$\frac{1}{\omega_x^2}=\frac{w}{g}y_{xx}dx$$

where y_{xx}=deflection at x due to unit load there.

Then natural frequency is given by

$$\frac{1}{\omega^2}=\int_0^l\frac{w}{g}y_{xx}dx.$$

For a cantilever shaft

$$y_{xx}=\frac{x^3}{3EI}.$$

Therefore

$$\frac{1}{\omega^2}=\frac{w}{g}\int_0^l\frac{x^3}{3EI}dx$$

$$=\frac{w}{g}\times\frac{l^4}{12EI}.$$

Therefore

$$W_e=\frac{wl}{4}.$$

The three methods described, for finding the equivalent weight, have given values of

$$\frac{1}{4\cdot24}, \quad \frac{1}{4\cdot15} \text{ and } \frac{1}{4}$$

times the weight of the shaft respectively. Although the differences appear to be of the order of 6 per cent, in a practical case this is not so. For instance, for the experiments described below the mass of the rotor is 0·095 lb and the mass of the shaft 0·167 lb. The equivalent masses at the end of the shaft from the three methods described are therefore 0·1344 lb, 0·1352 lb and 0·1367 lb respectively, giving a maximum difference of less than 2 per cent. For the experiments concerned with rotors of large inertia, the rotor mass was almost six times that of the shaft, which would reduce the percentage error even more.

The calculation of the equivalent weight of a cantilever shaft fitted with a flexible outrigger bearing is carried out by extending the foregoing treatment. A practical case applicable to the model rig described later is given below.

The Calculation of the Equivalent Weight

of a Cantilever Shaft Fitted with a Flexible Outrigger Bearing.—The available data are :

Length of shaft l	$=12$in
Weight of shaft	$=0\cdot1671$ lb
Distance of outrigger bearing from fixed end a	$=10$in
Measured stiffness at rotor	$=31\cdot4$ lb/in
Measured stiffness of shaft alone	$=9\cdot5$ lb/in
Elastic modulus for shaft material	$=28\cdot4\times10^6$ lb/sq. in.

The spring stiffness of the outrigger bearing can be found as follows, assuming a load of 31·4 lb to be placed at the rotor with the outrigger bearing removed.

Deflection under load :

$$y_c=\frac{31\cdot4\times1728}{3\times28\cdot4\times\frac{\pi}{64}\times\frac{1}{256}\times10^6}$$

$$=3\cdot32\text{in.}$$

Therefore the effect of the outrigger bearing is to reduce this deflection by 2·32in.

That is, if P is the force exerted by the outrigger bearing producing a deflection of 2·32in at the rotor, then

$$2\cdot32=\frac{P\times1728}{6\times28\cdot4\times10^6\times\frac{\pi}{64}\times\frac{1}{256}}\cdot\frac{100}{144}(3-0\cdot8333)$$

or

$$P=29\cdot2\text{ lb.}$$

The deflection at the outrigger bearing for unit deflection at the rotor is given by

$$EI\frac{d^2y}{dx^2}=W(l-x)-P(a-x)\text{ from }x=0\text{ to }x=a.$$

Therefore,

$$EIy=W\left(\frac{lx^2}{2}-\frac{x^3}{6}\right)-P\left(\frac{ax^2}{2}-\frac{x^3}{6}\right).$$

For unit deflection at the rotor $W=31\cdot4$ lb. Therefore, deflection at bearing ($x=a=10$in).

$$=\frac{1}{EI}31\cdot4(600-167)-29\cdot2(500-167)$$

$$=0\cdot710\text{in.}$$

Therefore spring stiffness

$$=\frac{29\cdot2}{0\cdot710}=41\cdot1\text{ lb/in.}$$

To find the equivalent weight of the shaft proceed as follows : —

Consider a uniformly loaded cantilever

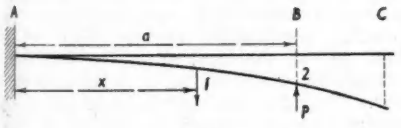

Fig. 3

A, B, C (Fig. 3), with a flexible prop at B exerting an upward force P. Let w=the load per unit run along the beam.

Let

Y_{11}=deflection due to unit load at any point 1 on the beam.
Y_{22}=deflection due to unit load at B.
y_{11}=deflection due to unit load at any point 1 with springs removed.
y_{22}=deflection due to unit load at B with springs removed.
y_{12}=deflection at point 1 due to unit load at point 2.

By the reciprocal theorem :

y_{21}=deflection at point 2 due to unit load at 1=y_{12}
S=stiffness of springs at B.

Then

$$Y_{11}=y_{11}-SY_{22}y_{12} \quad . \quad . \quad . \quad . \quad (5)$$

and

$$Y_{22}=y_{12}-SY_{22}y_{22} \quad . \quad . \quad . \quad (6)$$

From (2)

$$Y_{22}=\frac{y_{12}}{1+Sy_{22}}.$$

Therefore, substituting in (1) for Y_{22},

$$Y_{11}=\frac{y_{11}+S(y_{22}y_{11}-y_{12}^2)}{1+Sy_{22}}.$$

Using the Dunkerley theory for the natural frequency of a beam with a number of loads, which in this case is applied to a continuously loaded beam, we have :

$$\frac{1}{\omega^2}=\int_0^l\frac{w}{g}Y_{11}dx\,.$$

Between A and B

$$y_{11}=\frac{x^3}{3EI},\quad y_{22}=\frac{a^3}{3EI},\quad y_{12}=\frac{x^2(3a-x)}{6EI}.$$

The above being standard deflection formulæ for loaded beams.

Therefore,

$$Y_{11}=\frac{\frac{x^3}{3EI}+S\left(\frac{x^3a^3}{9(EI)^2}-\frac{x^4(3a-x)^2}{36(EI)^2}\right)}{1+\frac{Sa^3}{3EI}}.$$

From which we have

$$\int_0^a\frac{w}{g}Y_{11}=0\cdot053w.$$

Between B and C,

$$y_{11}=\frac{x^3}{3EI},\quad y_{22}=\frac{a^3}{3EI},\quad y_{12}=\frac{a^2(3x-a)}{6EI}$$

and

$$Y_{11}'=\frac{\frac{x^3}{3EI}+S\left(\frac{a^3x^3}{9(EI)^2}-\frac{a^4(3x-a)^2}{36(EI)^2}\right)}{1+\frac{Sa^3}{3EI}}.$$

from which we have

$$\int_a^l\frac{w}{g}Y_{11}'=0\cdot054w.$$

Therefore,

$$\frac{1}{\omega^2}=\int_0^a\frac{w}{g}Y_{11}dx+\int_a^l\frac{w}{g}Y_{11}'dx$$

$$=0\cdot107w.$$

If W=equivalent ωt of shaft, then

$$\frac{1}{\omega^2}=\frac{W}{S_c}$$

where S_c=stiffness of beam at C.

Therefore,

$$0\cdot107w=\frac{W}{S_c}=\frac{W}{31\cdot4}.$$

Therefore,

$$W=3\cdot36w$$

$$=0\cdot038\text{ lb.}$$

Therefore, by adding 0·038 lb to the rotor allowance will be made for the weight of the shaft.

The Critical Speeds of a Shaft Rotating in Bearings Having Asymmetric Flexibilities

Consider now a shaft supported by rigid bearings at one end and at the other end by a bearing held by two pairs of springs of different stiffnesses in the horizontal and vertical directions. Let a rotor of mass m and eccentricity h be attached to the shaft. Let the horizontal and vertical stiffnesses of the shaft at the rotor be c_1 lb/in and c_2 lb/in respectively. Referring to Fig. 2, let 0 be the static elastic centre of the shaft at the point of attachment of the rotor, E be the displaced position of the elastic centre at time t, and M the centre of gravity of the rotor. Then, as before, the equations to the motion in the X and Y directions will be

$$m\ddot{x}+b_1\dot{x}+c_1x=mh\omega^2\cos\omega t$$

and

$$m\ddot{y}+b_2\dot{y}+c_2y=mh\omega^2\sin\omega t$$

where b_1 and b_2 are the damping coefficients appropriate to the two axes.

The particular solutions to these equations are the same as before,

$$x=\frac{mh\omega^2}{\sqrt{(c_1-m\omega^2)^2+b_1^2\omega^2}}\cos(\omega t-\beta_1)\left(\tan\beta_1=\frac{b_1\omega}{c_1-m\omega^2}\right)$$

$$\quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and

$$y=\frac{mh\omega^2}{\sqrt{(c_2-m\omega^2)+b_2^2\omega^2}}\sin(\omega t-\beta_2)\left(\tan\beta_2=\frac{b_2\omega}{c_2-m\omega^2}\right)$$

$$\quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

For any value of ω

$$x=A\cos(\omega t-\beta_1)\text{ where }A$$

$$=\frac{mh\omega^2}{\sqrt{(c_1-m\omega^2)^2+b_1^2\omega^2}}$$

$$=A\cos\beta_1\cos\omega t-A\sin\beta_1\sin\omega t$$

$$=A_1\cos\omega t+A_2\sin\omega t \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Similarly

$$y=B_1\sin\omega t-\beta_2\cos\omega t \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and eliminating ωt from (9) and (10) and substituting $A_1=A\cos\beta_1$, $A_2=A\sin\beta_1$, $B_1=B\cos\beta_2$, $B_2=B\sin\beta$, we have

$$B^2x^2+A^2y^2+2xyAB\sin(\beta_1-\beta_2)=A^2B^2\cos(\beta_1-\beta_2)$$

which represents an ellipse.

Similarly if damping is neglected we have

$$\frac{x^2}{A^2}+\frac{y^2}{B^2}=1.$$

From equations (7) and (8)

x is a maximum when

$$\omega=\frac{2c_1}{\sqrt{4mc_1-2b_1^2}}$$

$$=\sqrt{\frac{c_1}{m}}\text{ (neglecting damping),}$$

y is a maximum when

$$\omega=\frac{2c_2}{\sqrt{4mc_2-2b_2^2}}$$

$$=\sqrt{\frac{c_2}{m}}\text{ (neglecting damping).}$$

For this case there will thus be two critical speeds given by

$$\omega=\sqrt{\frac{c_1}{m}}\quad\text{and}\quad\omega=\sqrt{\frac{c_2}{m}}$$

neglecting damping and the elastic centre of the shaft will describe an ellipse. At speeds below the first critical, both c_1 and c_2 are less than $m\omega^2$ and therefore x and y are both positive. The shaft will therefore whirl in the direction of rotation. However, between the two criticals x will be negative and y positive, which means that the shaft will whirl in the reverse direction to the rotation. Above the second critical both x and y will be negative

and the whirl will be forward again. Also below the first critical the centre of gravity of the rotor will be remote from the static elastic centre, relative to the actual centre, and above the second critical the centre of gravity of the rotor will lie between these two points, approaching the static elastic centre as the speed increases.

Using the same basic assumptions as before, the theory has again described completely the nature of whirl of this system for any speed of rotation.

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(To be continued)

Fatigue Tests on Glass-Fibre-Reinforced Plastics

By N. G. CALVERT, Ph.D., B.Eng., A.M.I.Mech.E.*

Two series of tests have been carried out using Wöhler fatigue testing machines. The first series used two-point loading giving uniform axial distribution of direct stress and zero shear stress. The second series used single-point loading with a very short cantilever arm; in this case it was inferred that shear stress was the significant factor. In each case specimens have been tested statically under corresponding conditions of loading. The results are consistent with the following statements :— (1) *The material is liable to fatigue ;* (2) *the fatigue limit strength on a* 50,000,000 *basis is approximately* 12 *per cent of the static strength.*

GLASS-fibre-reinforced plastics are relatively new materials of great versatility. Their static strength is considerable and they have valuable properties as regards resistance to corrosive, organic and chemical attack. There is, however, as yet, very little published information as to their fatigue properties. The following is an account of a preliminary attempt to apply an established method of fatigue testing to one of these materials.

Nature of Material

The material is necessarily less homogeneous and isotropic than normal metals ; indeed, depending on the method of reinforcement used, the properties may be highly directional. Stress calculations based on homogeneity and isotropy may have only a limited validity. To reduce the number of variables in the first instance " rovings rods " were selected as test specimens. These have the advantage that all the fibres lie parallel to the axis of the bar and random variations in properties can be expected to be less than with other types of reinforcement. Further, quite definite stressing conditions can be applied. Thus, direct axial stresses should not test the bond between the fibres and the resin : the two component materials being subject to the same strain while the stresses will be in the same proportion as the respective elastic moduli. Alternatively, a lateral shear has a complementary shear stress which is a direct test of the bond between the glass and the resin. The rods used were of commercial quality and were not specially manufactured for the tests. The glass content was approximately 46 per cent by weight and the resin used was that known as " Crystic 300."

Wohler Test Specimens

The methods of test were based on those used in the fatigue testing of metals. In the first instance, a rotating beam, or Wöhler type test with two-point loading was employed. In this test the specimen projects axially from a rotating chuck (Fig. 1), and it is loaded by equal and opposite forces *P*. The effect is to subject the test length to a

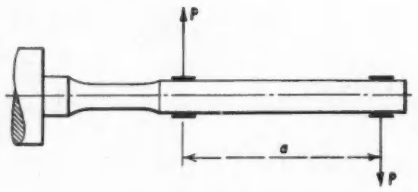


Fig. 1

uniform bending moment of magnitude $P \times a$. Since the loads are equal and opposite there can be no shear applied to the test length. At each rotation of the specimen the stress at any point on its surface varies cyclically between equal positive and negative limits. In metal testing the test portion is normally reduced in diameter to localise the fracture.

The first specimen to be tested was prepared as a metal specimen would be—that is, a parallel length of 1in was turned down from the bar size of 0·5in to 0·4in, the ends having the usual generous transition radius to the full diameter. This test showed failure by the separation of the upper layers at the ends of the test section where the reinforcing fibres had been cut and their ends left exposed. Later tests were carried out on the parallel ½in diameter bars. They were mounted in split steel collets which were bell-mouthed to reduce damage by crushing on the surface of the specimens.

Test Results

Test results by the two-point loading method are tabulated below. The stress values are calculated as for a homogeneous elastic substance :

Stress, lb/sq. in	Endurance, millions of cycles
15,020	1·086
15,000	0·700
15,000	0·385
14,000	0·712
12,750	10·600
10,300	19·570
10,200	27·400
7,850	57·200 unbroken

A static test under the identical type of loading gave a breaking stress of 70,000 lb per square inch. When the above results are plotted on a conventional S-N field, as

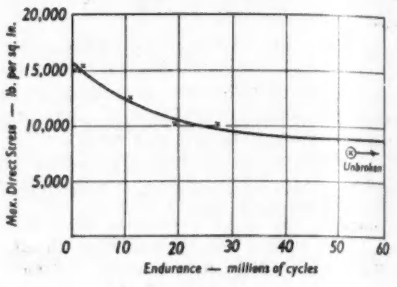


Fig. 2

in Fig. 2, they are consistent with a fatigue limit stress (on a 50,000,000 basis) of 8500 lb per square inch and a fatigue strength/static strength ratio of 0.12.

Shear Test Specimens

The direct application of a reversed shear is difficult, but a substantial shear plus a rather larger direct stress can be applied by using a very short rotating cantilever with single-point loading. In the diagram (Fig. 3),

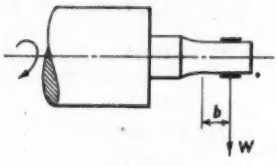


Fig. 3

the bending moment is $W \times b$ and the mean shear stress is W/A, where A is the area of cross section. Thus, by making the arm b short enough it should be possible to devise a test in which shear prodominates. In practice, mechanical considerations set a limit to the shortness of b. (In the tests recorded b was 0·6in on a 0·5in diameter bar.) Provided that the test portion is long enough for St. Venant's principle to be applied, then the direct stress is a maximum at the outer fibres and the shear stress is maximum at the neutral axis. Furthermore, if the material is homogeneous, elastic and isotropic, then it can be shown that the maximum shear stress in a bar of circular section subject to lateral load is one-third greater than the mean. In the tests recorded not all the above conditions were satisfied. The stress values given should be regarded as safe bases for comparison rather than exact mathematical values. Since the direct stresses in the short cantilever tests are within the safe range as established by two-point loading, it is inferred that in these tests the fractures are all due to shear stress.

Test Results

Test results are tabulated below :

Direct stress, lb/sq. in	Shear stress, lb/sq. in	Endurance, millions of cycles
7,500	1,040	0·331
6,300	870	3·350
5,050	700	16·500
5,050	700	10·600
3,550	496	57·600 unbroken
Static test under identical conditions of loading :		
39,000	5,400	

* Lecturer in Mechanical Engineering, the University of Liverpool.

When the above are plotted on a conventional S-N field (Fig. 4), there is considerable scatter, but an approximate curve has been drawn which is consistent with a fatigue limit (on a 50,000,000 basis) of 600 lb per square inch in shear and a fatigue strength/static strength ratio of 0·11. All the fatigue fractures were sensibly normal to the axis of the rods. The zero shear static tests failed initially by crushing at the points of load application and the short cantilever tests by longitudinal shear. All the fatigue test pieces showed fretting damage where they were in contact with the steel collets of the machine.

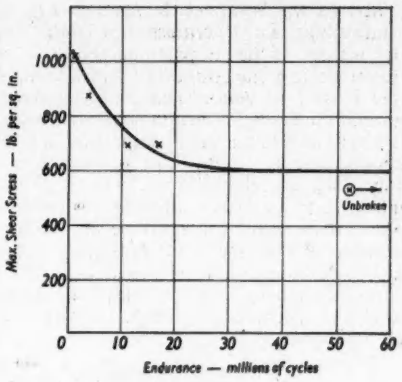


Fig. 4—Short cantilever loading in which shear is significant

Discussion

The tests using two-point loading were carried out at a speed of 1600 r.p.m. and those on the short cantilevers (significant shear) at 1000 r.p.m. The possibility has not been overlooked that heat may be developed due to internal hysteresis and that the resulting temperature rise may be such as to influence the properties of the resin. (This would apply particularly to the tests with significant shear since the maximum shear stress is on the neutral axis, while the maximum bending stresses occur on the surface where cooling is most effective.) If this is so, the material will have a "speed effect"—that is, the endurance will be a function of both the stress and the speed of testing. The most favourable conditions for the resin might occur at very low speeds (where endurance is of minor importance except for short life applications), and as the speed of testing is increased the endurance may be expected to fall. The justification for the speeds used is to compare the glass fibre reinforced resin with established materials under the same conditions. There is also the practical problem of the machine time required for each test. Some of the test runs recorded took nearly six weeks to complete.

Acknowledgments

The author wishes to thank Professor W. J. Kearton, D.Eng., M.I.Mech.E., M.I.Mar.E., for permission to carry out the work in the Mechanical Engineering Laboratories of the University of Liverpool, and Fibreglass, Ltd., Ravenhead Works, St. Helens, for the supply of test material.

Iron and Steel Institute

AUTUMN MEETING

No. II—(*Concluded from page* 485, *October* 4)

DURING the autumn meeting of the Iron and Steel Institute, held in London, the afternoon's business was conducted in two separately held sessions running concurrently. The session at which Messrs. Middleham, Rait and Colbeck presented their paper on high-boron steels was also open to members of bodies comprising the British Nuclear Energy Conference.

After the main business of the day an evening lecture was delivered at the Royal Institution by Professor J. M. Kay, Professor of Nuclear Power at the Imperial College of Science and Technology. The subject was "The Future Engineering Development of the Gas-Cooled Nuclear Reactor," and the lecture was open to attendance by members of bodies comprising the British Nuclear Energy Conference. A summary of Professor Kay's address is given on page 526.

HIGH-BORON ALLOY STEELS

By T. H. Middleham, J. R. Rait, D.Sc., F.I.M., F.Inst.Ceram., A.R.T.C., and E. W. Colbeck, M.A., F.I.M.

Synopsis

Before the advent of nuclear reactors little interest had been shown in boron alloy steels because the difficulties of working them were insurmountable and their extreme brittleness rendered them unsuitable for structural or engineering use. Since boron has a very high thermal neutron-capture cross section, nuclear engineers became interested in using alloys containing substantial amounts of boron for "control rods" and for general shielding duties in thermal nuclear reactors. This paper describes the discovery of a new technique for the production of boron-iron alloys containing up to about 4·75 per cent boron which can be successfully forged, rolled and extruded and boron-iron alloys up to about 6 per cent boron which can be successfully produced in the form of castings. The methods of manufacture, physical and mechanical properties, and constitution of these boron steels are described as well as their applications in thermal nuclear reactors.

Discussion

Mr. C. T. Harris (William Jessop and Sons, Ltd.): Nuclear energy has provided many new problems in non-ferrous metallurgy, but surprisingly few challenges in ferrous metallurgy. The demands made by the nuclear power industry are very light compared, for instance, with the demands of the jet engine, which posed so many problems that the whole development was held up for many years. It is almost tempting to say that Whittle had to go to Hadfield's to find a steel to make his engine work, whereas on nuclear power plant they have had to go to Hadfield's to find a steel to *stop* it from working.

We agree completely with the findings of Mr. Middleham and his colleagues that the limit of forgeability is about 4 per cent under normal conditions. It is interesting that this is about the eutectic composition, and I wonder whether the authors have any comments on the significance of this. They have drawn attention to the very interesting effect of aluminium, but I should like to ask how far this is affected by the other functions of aluminium, because, although there are no figures quoted for very low aluminium, it almost looks as though the level of aluminium necessary is merely that which will tie up the oxygen and the nitrogen.

Shell moulding certainly can be applied with some effect to these alloys, but since the authors work with very low-carbon steel I ask whether there is a carbon reaction such as often takes place in low carbon steels?

These alloys rust extremely easily. For certain reasons we have diverted our attention to seeing whether we could put substantial amounts of boron into stainless steel. This is possible, and you can put pretty well the same amounts of boron into both ferritic and austenitic stainless steels without too drastic an effect on forgeability and mechanical properties. In 12 to 13 per cent chromium steels, for instance, we can put in 2½ to 3 per cent of boron, and the material is still forgeable. This also applies to austenitic steels of the 18/8 or the rather richer alloyed types.

I was a little disappointed to find no reference to the mechanical properties of these steels. We have done a fair amount of work on mechanical properties. With a dead low-carbon steel, if the boron is 0 per cent the proof stress is about 7 tons per square inch, the maximum stress 19 tons per square inch, and the elongation 50. The figures for 2 per cent, 3 per cent and 1 per cent boron are :

Boron	Proof	Maximum	Elongation
1	8	27	26
2	16	37	9
3	20	49	4

Mr. Middleham said that with 2 per cent boron there is about 3 per cent elongation, whereas we report that with 2 per cent the elongation is about 9 per cent and with 3 per cent boron it is about 4 per cent. At 4 per cent boron there is less than 1 per cent elongation. If, instead of a pure iron base, we use 13 to 14 per cent chromium, with 2·4 per cent boron we get 60 tons tensile per square inch and 5 per cent elongation. Of course, 4 to 5 per cent elongation is the sort of elongation which engineers are usually prepared to use, if they have to. This occurs at 2·4 or 3 per cent boron.

If we use a base of 19–Cr, 14–Ni, 1·5–Nb, then we get :

Boron	Proo	Maximum	Elongation
0...	13·5	38	52
1...	14·4	43	25
2...	18·8	48	8

Dr. A. B. McIntosh (U.K. Atomic Energy Authority): The satisfactory development of high-boron alloys has played a significant part in the progress made in nuclear power production. In the BEPO reactor the control rods were made of a boron compound in a tube not, as is said in the paper, of boron steel. But when we came to the Windscale piles we felt that it would be best if we could obtain a steel with the necessary strength containing the necessary neutron stopping materials and of the desired oxidation resistance. The physicists told us that we had to get at least 2 per cent boron into the material.

I approached five of the principal steel-making companies in the country. Development was initiated in three centres, Hadfield's, Jessop's and Firth Brown's. The work soon disclosed the very great difficulty in the forging of these alloys, particularly as the boron content increased. We had hoped to get a bar about 30ft long, but it was soon apparent that in the very rigid time schedule which we had to obey we were unlikely to achieve this in time.

In view of the difficulties which we felt might be experienced with oxidation resistance, we raised the question of stainless steel containing boron. The authors' company made a few trial casts and we soon found out that the toughness and impact resistance were likely to be low. We could not tolerate the possibility of any of the steels flaking off from any cause, so we put the bits of boron steel in a stainless steel tube.

In Calder Hall the engineers wished to

suspend the control rods from cables and, therefore, they wanted to cut down weight. By this time we had learned that boron is effective only in the surface, so that the middle adds unnecessary weight. In view of other factors, however, the boron content had to be increased. We requested a minimum of 5 per cent boron, which was not achieved in the time available, but it is pleasant to note that, with our material, according to the paper, the permissible amount is now nearly 5 per cent.

Mr. J. E. Russell (English Steel Corporation) : The authors say that they found very little effect with heat treatment, except a slight granulation of the structure at about 1100 deg. Cent. We have found that by what might be called a sub-critical treatment —that is about 850 deg. Cent., a little below the alpha-gamma change as shown on the best of the three diagrams—the eutectic becomes very much more broken up and coagulated into an irregular mixture of Fe_2B and ferrite. There is a slight softening from about 460 DPN to about 430 DPN.

The equilibrium diagram of these alloys is, in my opinion, still very confused in the lower temperature ranges. Both the Hannensen and the Tschischewsky and Herdt diagrams identify the magnetic change at 760–770 deg. Cent. with an actual phase change. It is probably simply a magnetic to a non-magnetic alpha change, rather like the alpha to beta change in pure iron.

I should like to comment on the extremely interesting graph showing the effect of the aluminium on the forgeability. We have the impression that the curve shown is not merely the boundary of forgeability, but is also that of room temperature brittleness. The effect of aluminium is quite startling with about 4½ per cent boron steel. If there is no aluminium present, two sticks of the steel tapped together will shatter. With about ½ to ¾ per cent aluminium, a large amount of energy is required to break them.

Mr. E. Fanthorpe (A.E.I.-John Thompson Nuclear Energy Group) : My main concern is with the possibility of providing a boron steel lining inside a pressure vessel of the Calder Hall type. In this case it is not only a fact that boron has a high thermal neutron cross section, but also that radiation is easily captured. There are four possible advantages in so using the boron steel. The first is that it would increase the possibilities of inspecting the pressure vessel when the reactor is shut down. A reduction to about 10 to 20 per cent of the dose rate can be obtained by using this lining as an inner lining. Secondly, the heating effect of the radiation on the pressure vessel can also be reduced to about 10 to 20 per cent of that without a lining. Thirdly, we can also reduce the heating effect on the concrete of the biological shield, which may be of some importance. This can be reduced by about 20 to 30 per cent. Lastly, and not very important in this case, we can reduce the thickness of the concrete very slightly.

Those are the advantages from the shielding point of view. There are a number of disadvantages. The first is the difficulty of support of the boron steel liner. Secondly, there must be no possibility of the escape of boron into the gas stream, and therefore we need to clad the boron steel liner.

The figures which Mr. Harris produced showed that with 1 per cent boron we can get very good mechanical properties. If this were made into 1 per cent boron-10, presumably there would be the same mechanical properties with effectively five times as much neutron absorption, because boron-10 is the isotope which is important.

Mr. L. M. Wyatt (U.K. Atomic Energy Authority) : Dr. McIntosh has dealt with the history of the original manufacture of boron steel for the Authority, but I thought that I could tell you something of the background. In designing an atomic pile it is essential to be able to put into their path as large an area as possible of the material which will stop and absorb neutrons. In addition, unfortunately, and as a contradictory requirement, the control rod must be as small as possible to save space. It must not be too heavy, because sometimes you want to move it rapidly and to stop it quickly. It should have the mechanical strength to withstand inertia forces.

The materials which would fulfil all these contradictory requirements are gadolinium, europium and samarium, three rare earth metals which are distinctly expensive, and cadmium, which melts at rather a low temperature. Alloys of cadmium, silver and indium are being developed now, and they may be competitors for boron, but obviously an alloy containing silver will be comparatively expensive. Lithium and hafnium might be used, but you can get hafnium only if you use large quantities of zirconium, as the Americans do. Out of these rather unpromising materials you must produce a sound engineering material, and boron is by far the cheapest and most readily available. The obvious thing to use, therefore, was boron steel.

As Dr. McIntosh hinted, 5 per cent boron steel is required only in a comparatively thin material. If you have a quarter of an inch of it, this will stop all the neutrons that come into its path. It is fairly satisfactory in that respect, and with the Calder Hall reactors it is fairly easy to fit in. In a water reactor you would need something rather thinner, and you would be in difficulties. You could probably get over this by using enriched boron ; as the representative from Rolls-Royce said, the important agent is boron-10. It is possible to enrich the outside, and the process, compared with other diffusion processes, is not too expensive. You can get a much higher concentration of boron-10 in the steel.

A reactor which is to have a control rod right through it while it is working is a bad reactor, because the control rod is absorbing expensive materials. Boron with neutrons produces alpha particles which become helium. If we think of the Calder Hall type of control rod, with the 5 per cent, and make some slightly pessimistic assumptions as to the amount of radiation it will have during its life, we shall find that for 10 per cent burn-out of boron, 6 cubic centimetres of helium will be produced for every 1 cubic centimetre of the original material. We have not burned out boron steel to this amount yet, but various calculations which we have made on fuel elements show that the boron steel might tend to swell or break. The alpha particles damage the lattice and cause it to be very brittle at low temperatures. If we build these higher rated reactors, even on the 5 per cent boron-10, we shall get the 10 per cent boron burn-out much earlier in the life of the reactors, and the tips of the control rods will need to be changed somewhere between one and four years. If we want higher concentrations, we may have to go to other methods. The most hopeful is the dispersion of boron carbide in steel, which would presumably have to be made by powder techniques. Thus one would expect to get considerably higher quantities of boron and a considerably higher burn-out.

Mr. D. A. Oliver (B.S.A. Group Research Centre) : I was very intrigued by the discussion, especially when Dr. McIntosh pointed out that with these highly absorbing materials in thin tubular form the outer layers did all the work. To what extent do we want ductility in annular tubular sections ? What are the objections to putting a high-boron material inside a stainless tube made in the ordinary way, apparently economically and reliably, and filling it with annular rings of a high absorbing material ?

The Chairman : Many figures have been quoted for the elongation of various boron-containing materials, which I assume are all figures for the material before it has been subjected to irradiation. Surely what is more important is the rate of decay of that elongation. What we want is a material in which the rate of decay in ductility is the least, not necessarily one which starts with the highest figure.

Dr. McIntosh : There is a little confusion here, because we do not specify ductility figures. It is most unlikely that any responsible engineer would run the risk of putting a moving rod into a reactor where there is a possibility, for any reason whatever, that some part of that rod could detach itself and poison his reactor. At present, we put bits inside a tube, where we know where they are and where they will remain. I think the best answer to the chairman is to say that the question does not arise.

Mr. Middleham (in reply) : I should like to deal with most of the points in writing. We have found it very difficult to get information about what happens to these rods after a certain length of service. All I know is that some of the 2 per cent boron which we supplied a long time ago is still functioning, and presumably everybody is happy.

PROPOSAL FOR A SELF-LINING BLAST-FURNACE

By W. A. Archibald, Ph.D., F.Inst.Ceram., T. P. Brown, and L. A. Leonard, B.Sc., A.R.I.C.

SYNOPSIS

The blast-furnace has been considered as a pipe through which granular materials flow. Its behaviour has been examined by a theoretical approach, model work, and observation of blown-out furnaces. The mechanisms of wear, hanging, and scaffold formation have been outlined. This work has led to proposals for a self-lining furnace in which baffles trap material from the charge to act as a self-renewing refractory lining, and stack tuyeres are used to control hanging and scaffolds.

DISCUSSION

Professor M. W. Thring (Sheffield University) : Here we have the Head of the Refractories Division in B.I.S.R.A. saying " Don't use refractories "—and that, in a nutshell, is the story. I must say that I think it is a very good story. I think the one thing that Dr. Archibald did not tell us is whether anybody is going to do it, and that is the really

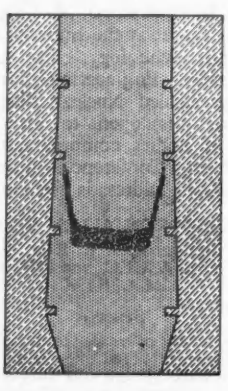


Diagram drawn from one of Dr. Archibald's illustrations, showing granular flow past shelves in a blast-furnace-shaped pipe

important question. I sincerely hope they do, because I think we have here something that is very interesting and very well worth trying. I hope that it will not be left to the Russians or the Czechs to do it first.

Dr. Archibald has used model techniques, and I think that I recognised cornflakes and puffed wheat among his model materials! Obviously, to make a satisfactory model of what happens in the blast-furnace is extremely difficult, if not impossible, because there are too many things happening. One of the things that I have always been hoping to see was a model with actual melting of the material going through. We at Swinden House have been playing with paraffin wax models of counterflow steel melting. I think that the models of the blast-furnace will be more useful when the full process is simulated by genuine fusion.

I did not think Dr. Archibald studied quite sufficiently in his model the distribution of gas flow. One of the most important questions is whether the gas goes into these nice little spaces between the shelves or not; it is no use having a layer of material there if the gas velocity in that region is just as high as everywhere else, because then you have heat release near walls and get heat loss just the same. No doubt Dr. Archibald will answer that once the particles are in there they will take the reaction as far as they can and then stay like that; but I am not quite convinced.

I feel that Dr. Archibald is a little optimistic with the spacing of his shelves. It may work in a model, but one wonders how far it is going to work on the full scale. Another point is that these shelves are water-cooled. If the shelves are such a distance apart that their surface area is equal to the surface area of the wall in between, then you might not be any better off than with a bare wall, so far as heat loss is concerned.

I think that the stack tuyeres are very interesting, although obviously from the thermodynamic point of view they are quite wrong; they are going against the whole principle of the blast-furnace, which is to keep the flow of the gases going up and the charge coming down; as soon as you put in some heat half-way up the stack, you put up the overall fuel consumption; one hopes it will never be done for very long or very often.

Finally, I revert to the question of who is going to try this, because that is always the major problem in research of this kind. In some cases the answer is the pilot plant, a plant not so big that it costs millions, but big enough to try out the thing and prove to the full-size plant people that it will work; but that process itself costs tens of thousands of pounds. In introducing the paper, Dr. Archibald mentioned how all this work came from the cupola and I therefore think that one answer would be to go back to the cupola people and persuade them to do it. But I do not think that is the right answer in this case. I think that we have got to find somebody with the courage to try it on at least a full-sized blast-furnace, even if it is only a little one. I hope to hear later on that somebody is going to do that. Dr. Archibald has made it very easy for them in the paper, because he says that they can have a brick lining as well, so they will have belt and braces with this thing, and when the brick lining goes his process will solve the problem.

Mr. G. H. Johnson (Kettering Iron and Steel Company, Ltd.): The authors appear to agree that effective work has been done to deal with conditions in the bosh and hearth, and their present proposals relate to the shaft where, admittedly, the problems are greatest. All along we have kept our eye on the development, mainly in Central and Eastern Europe, of thin-walled shafts irrigated with water. I witnessed early experiments in Czechoslovakia as long ago as 1930.

When considering shaft construction, we must bear in mind the great changes which have taken place in the duty which the shaft lining has to perform. At present the major development in blast-furnace practice is a progressive increase in the degree of burden preparation with efficient removal of fines and a corresponding increase in the percentage of sinter charged. The whole volume of the shaft has been brought into action, with substantial increase in output and reduction in coke consumption. The new pattern of burden preparation gives much greater action at the inwalls, and the sand-blast effect of gritty particles in the ascending gas, coupled with abrasion by hard coke and sinter, has led to intense physical attack on the refractory lining. Over a period of years the refractory makers have improved their bricks, but they are now faced with the demands imposed by modern furnace practice.

The authors of this paper propose a brickless construction utilising the refractory nature of the charge, and state that it is based on the fact that granular material can serve as a refractory if it is held in position under compression. Thus, material from the burden can be made to act as a lining *provided* it is a stationary coherent mass, and *if* it can be held on the walls, and *if* it develops suitable properties. It is, of course, conceivable that all these conditions could be met, but a practical design has yet to be evolved, and until this emerges—and the idea of making the shaft "live on its own muck" has been turning over in people's minds for a long time—I would hesitate to advocate a departure from the modern refractories and modern methods of shaft construction which have been developed by long-term experience and investigation.

Mr. H. W. Richardson (British Ceramic Research Association): There is a great deal in the paper about the formation of scaffolds and how to get rid of them, but I think that a bigger difficulty with this construction would be to stop the wear of the lining. I think that we might find that the formation of a scaffold on such a lining would be a godsend.

I was pleased to hear the suggestion that, if we do try out Dr. Archibald's ideas in practice, there should be some bricks in the lining. I have felt for a long time that the linings have been too thick. I feel that if we had just a foot of brickwork, instead of 3ft, in a blast-furnace, that would be a good thing.

Mr. W. S. Debenham and Mr. J. B. Wagstaff* (United States Steel Corporation): It would seem that detailed discussion of this paper might well be divided into two parts. First, will the solid material cling to the sides of the furnace as it does in the model, and second, if it does, are there any practical considerations that have been overlooked? In regard to the first point, we are at the disadvantage that two years ago we thought we knew just how the charge descended the furnace, but now we are much less certain. One feels that shelves 2ft wide spaced 10ft apart would not be enough to hold a layer 2ft thick of coke and other "stable" charge in a stationary position against the furnace walls. There is some evidence, from the use of additional coolers in a hot spot of a furnace, for thinking that the charge would move around the proposed shelves. On the other hand, Dr. Archibald's experiments *seem* sound. It must be realised when discussing this type of model that the laws of modelling of granular solids are not known with certainty. It is usually assumed that the ratio of model size to particle size is of no significance as long as it is above about 30. This has not been definitely proved. Again, Dr. Archibald has worked with a homogeneous charge of granules. A blast-furnace charge is by no means homogeneous. Particle density as well as particle size vary widely from place to place at any one time. The pressures between the particles of a granular bed are not fully understood in the simple case of a homogeneous stationary bed. Very little work appears to have been done on a moving bed and none on a non-homogeneous bed. Under these conditions, it would seem wise to be very cautious about extrapolating from these models to a working furnace.

We have had several unpleasant surprises when attempting to predict the behaviour of a non-homogeneous bed from experience of a homogeneous one. In particular, in a bed containing columns of granules of different densities, it seems that the heavier column may move somewhat faster than the lighter ones. We also feel that transport of fine material within the coarser matrix of the main charge is probably important. Little seems to be known about either of these phenomena.

In one or two places, Dr. Archibald's conclusions are not borne out by our experience. For example, he states that "hanging cannot occur unless extensive agglomeration of the granules takes place." We have many times demonstrated hanging in model experiments without any agglomeration, but by using a dusty charge, particularly if it is charged in layers.

One wonders if the author has given adequate thought to the top of the furnace, where temperatures are such that the self-lining action may not function. Is it his idea to use conventional armour or a "tin top" construction, and would either be extended down to a point sufficiently below the stock-line to allow transition to the shelf construction without disturbing the furnace lines? This is a serious question, as it is essential to maintain smooth lines below the bell for good distribution and operation.

Has the author given full consideration to the volume of water required? By his formula, if it is desired to maintain a 2ft lining thickness, the average furnace would require six shelves completely circling the furnace at 10ft intervals. This will approximate 600ft of shelving all water cooled. This is about twice the amount used with stack coolers, even when these are extended up to 35ft above the mantle.

In our experience, the upper middle portion of the stack lining wears slightly, any difficulty being generally confined to the stockline area mentioned above and the lower stack zone. We are using stack coolers increasingly in the lower stack zone, carrying them to a height of 35ft above the mantle. It has been observed that while these coolers do help to maintain the original furnace lines, they do not always prevent the occurrence of hot spots resulting from poor gas distribution. The self-lining furnace might be expected to be more adversely affected under similar conditions, as the vertical spacing would be greater than with stack coolers. We experience little trouble from scaffolding, a fairly common difficulty in British furnaces; hence, it would seem that the self-lining idea would be more adaptable to their practice than to ours. This is particularly true when it is considered that American blast-furnace brick is substantially superior to any now available in England. On an average rebuild job, the

* Contribution read by Professor Thring.

cost of refractories rarely exceeds 15 per cent of the total cost of repairs necessary, and considering the cost of adapting a furnace to a self-lining construction, we believe there would remain very little economic incentive for this design unless the durability of other non-refractory parts of the furnace were substantially improved.

Mr. E. M. Summer (Stanton Ironworks Company, Ltd.): I hope that the poor attendance of blast-furnace operators at this meeting is due to the fact that they have already had an opportunity both of seeing the film and of discussing Dr. Archibald's ideas, and not to indifference on their part.

While we appear to have solved the problems of the hearth and the bosh by the use of carbon, we still have the problem of the stack with us, and very few would claim to be able to build blast-furnace stacks which can match up in useful life to the life achieved by the carbon in the lower parts of the furnace. At Stanton we get disintegration of the lining —we are not really troubled much by the formation of scaffolds—and I think that is increasingly so in this country. If we accept Dr. Archibald's theory of failure, then it must be true that in the lower half of the furnace above the lintel we can expect failure with our present means of construction, and that in order to combat this we ought to try to produce, at least in that area, a low inwall temperature to the stack lining. This problem can be tackled in several ways, either by using a material of high conductivity and building it right out to the casing, or by using a thin wall lining protected and supported by adequate cooling, or (as Dr. Archibald suggests) by putting in water-cooled shelves and putting in almost no lining at all.

Dr. W. A. Archibald (in reply): I should like first to make one general point clear. It was not our intention in this research to try fully to reproduce or understand what goes on inside the furnace from the point of view of making iron or slag. It was all done with a view to what is happening to the containing skin. Therefore, some of our assumptions were made as simple as possible. We did consider the question of having a melting model, and the idea of paraffin wax had occurred to us.

The major simulation in the model was merely this progress of the granular material down the furnace or up the furnace, and whether it its taken off towards the bottom part or part-way down by melting, or by apertures that allow it to leak out, should not, I think, affect the major assumptions.

Professor M. W. Thring: It was the scaffold effect that I was interested in from the point of view of melting. You cannot duplicate that with your technique.

Dr. Archibald: I should like to refer to Professor Thring's comments about the distinction between the two types of scaffold. I think that I have somewhat changed my footing since the paper was published, and I have become more convinced that the laminated type of scaffold is not a freezing but an iron deposition process. I think that Professor Thring's difficulty was that he could not imagine a freezing mechanism going up in a thin layer like that on the wall around the surface of the scaffold, and I think I agree with him. I feel that if there is a setting of liquids it must be due to something reasonably widespread in the nature of colder gases going up.

As regards the area of heat loss of the shelves, provided that this system does work as it is estimated from the models, then if you have a shelf as described, and if this material does become solid and impervious, then the only part offering much heat directly to the furnace is the nose of the shelf.

On the question of whether or not these apertures between the granules will become bunged up, if one does find that on a large scale these granules are kept stationary, it is almost as desirable that the gases should go through there in the initial stages of operation as that they should carry dust to make this impermeable. I see no difficulty in believing that, provided the skeletal structure is kept stationary, it will become congested with slag material if the dust-laden gases go through it. When we have taken samples, as indicated in the paper, from different parts in the furnace, we have found that, in measuring the permeabilities, these were very low indeed, and they could not have been so low when they were initially laid down.

I would imagine that the thickness of the wall could be something of the order of 1ft. The space dimensions between the shelves might be 5ft. I would not try to push those figures too seriously, because I think that accurate dimensions have got to come from full-scale work.

On the question of bricks in the furnace, I think that in order to approach this problem one has, mentally at least, to wipe out the bricks and see what would happen without them. I have become quite confident that one could operate a furnace in this way without bricks at all, but there would be the preliminary stage, before the pores got bunged up, when one would get much heat transferred to the walls, and one would need to have some cooling on the walls to carry over that period. But having regard to the nature of blast-furnace work, and the scale of it, I would certainly agree to seeing the trials carried out with bricks in. Possibly there would be quite a lot to gain by that sort of construction.

As regards Mr. Richardson's feeling that the thing to worry about is wear rather than scaffolds, I think that we must simply agree to differ. If there is wear, I am convineed that it will be less with this sort of fixed-point barrier in the path of the refractory than it will be without them.

Messrs. Debenham and Wagstaff maintain that on their model, using non-homogeneous particles, they can get scaffolding. Unfortunately, I am not familiar enough with the details of their experiments to be quite sure why that should be, because in our case there was never any tendency to hanging. If one considers it, a furnace like this is just a huge hopper, and if one has a huge hopper with an opening at the bottom to let out material, one would not expect any material of reasonably small size not to run out freely. My own feeling is that in their experiments it may be that if they do not allow the burden to descend while they are blowing gases in, they then allow the stationary burden to become blocked up with particles and to key the whole thing together into a compact. Providing there is no shelling, or some mechanism preventing the burden from moving in the first place, I see no reason why it should get so full of small particles as to block it in that way. You have got to have some process producing a monolithic arch to prevent it from falling down.

One of the criticisms of this work is that we do not have the thing to scale, and that it is too small. I would like to see a cooling model blast-furnace, but I hesitate to think that we can persuade anyone that it would be a good idea. If one used a hopper the shape of a blast-furnace, would one ever be able to get the material to hang ? I do not believe one would.

Future Engineering Development of the Gas-Cooled Nuclear Reactor

By Professor J. M. Kay

The first detailed investigation into the possibility of a large-scale nuclear power programme was carried out at Risley in 1953. It was realised that the programme would have to be based on the use of natural uranium at least for the first decade. It seemed that, for the United Kingdom, with the growing demand for electricity and the continuing inability to produce more coal, the need for large-scale nuclear power would come very suddenly and quickly. These considerations pointed to the gas-cooled graphite-moderated reactor, as this was the only type which could be regarded as a reliable engineering proposition and which could be fuelled with natural uranium. The reactors at Calder Hall provided the basis for the first stage of the programme.† It must be emphasised, however, that the design of the Calder Hall plant was optimised for plutonium production and that the period of irradiation required for the fuel elements was relatively short. For a commercial power-producing reactor it is essential to achieve (i) larger size of core, (ii) higher average heat rating in MW per ton of fuel, (iii) longer irradiation (2500 to 3000MWD per ton), and (iv) higher temperatures. Increasing the size of the core is probably the most important development at the present stage. It is certainly possible to construct a cylindrical pressure vessel of approximately 50ft diameter, using steel plate 3in thick, compared with the Calder Hall design of 37ft diameter using plate 2in thick. It should then be possible to accommodate an active core of diameter 40ft to 42ft, an increase of about 35 per cent, compared with the 31ft diameter at Calder. It should also be possible to increase the height of the active core, although not in the same proportion because of the pressure drop in the channels and the desire to avoid an excessive range of temperature between gas inlet and outlet. We might reasonably choose an active core height of 24ft to 25ft, an increase of about 15 per cent on Calder. We thus arrive at an active core volume approximately twice that of the Calder design. Taking the same lattice geometry and fuel rod diameter as at Calder, and noting that the Calder reactors each contain a charge of 130 tons of uranium, we arrive at a tonnage in the improved design of about 250 to 260.

The larger core will permit increased flattening of the neutron flux, resulting in higher average-to-maximum ratio for the fuel or channel heat rating. A radial average-to-maximum ratio of about 0·8 would not be unreasonable, permitting a useful rise in the average fuel heat rating. Combined with a slight advance in the permissible fuel element surface temperature, say, from 410 deg. to 430 deg. Cent., and with a slightly improved heat transfer surface for the can, it should be possible to step up the heat rating of the fuel by about 50 per cent over the Calder figure of 1·4MW per ton.

It will therefore be reasonable to take 2·1MW per ton as a typical average heat rating to-day. With 260 tons of uranium in the core, and thus a heat output of about 560MW, an overall thermal efficiency of about 27 per cent should give an electrical output of about 150MW per reactor.

It is important that this advance by a factor of more than three on the Calder Hall output is almost entirely a matter of engineering design. These developments, listed above

† See "Proceedings of Symposium on Calder Works Nuclear Power Plant," *Journal of British Nuclear Energy Conference* Vol. 2.

as items (i) and (ii), resulting in an electrical output of the order of 150MW per reactor, have already been achieved in the commercial designs now under construction at Berkeley, Bradwell and Hunterston.

It is also of the greatest importance, however, to achieve longer irradiation of the fuel (item (iii) above). This calls for great ingenuity. Perhaps the best policy here is individual support for the elements, and this is done in at least two of the first commercial designs. Also, for power station operation it is necessary to change elements while the reactor is under load. With the larger sizes of core under consideration, having approximately 3000 channels, an average heat rating of about 2·1MW per ton of fuel, and an irradiation level of 2500 to 3000MWD per ton, it will be necessary to refuel about two channels every day. It may also be worth while to re-shuffle some of the elements in the reactor to achieve more uniform irradiation. Fuel changing should thus be regarded as an almost continuous process. All present British commercial designs of gas-cooled reactor incorporate arrangements for routine fuel changing under load. This may well prove to be the biggest selling point for the gas-cooled reactor. No other kind of reactor at present envisaged as a serious engineering project can compete on this feature.

In spite of the publicity given to it, higher temperature (item (iv) above) is probably the least important current development. The higher thermal efficiency resulting from higher operating temperature may easily be offset by reduced reliability or decreased element life. It will certainly be necessary to proceed very carefully in this matter.

It may be of interest to consider how far the present basic design of gas-cooled reactor can be pressed without radical change in materials. The existing type of fuel element with a magnesium alloy can, but individually supported, should be advanced to a permissible surface temperature of 450 deg. Cent., and possibly 475 deg. Cent., but this appears to be the absolute limit. Some further improvement in heat transfer surface, together with still larger core size, should make it possible to count on a further advance in average heat rating, perhaps to 2·5MW to 2·8MW per ton. A specific rating twice that of Calder is probably the practical limit using solid metal rods and magnesium alloy cans. The pressure vessel makes the next outstanding demand on engineering skill. One hesitates to go much beyond a 70ft diameter spherical shell using steel plate about 3in thick. Careful design, however, may accommodate 300 to 400 tons of uranium fuel in the core. Taking 350 tons as typical, with an average heat rating of 2·5MW to 2·6MW per ton of fuel, the heat output should be about 900MW per reactor. With an overall efficiency of 28 per cent the electrical output would be approximately 250MW per reactor. A plant of this size, with a capital cost around £110 per kW, would immediately be competitive with any coal-fired power station in the U.K., and would also be a fully commercial proposition in most Western European countries. It cannot be too strongly emphasised that the gas-cooled reactor is the only type for which there is an immediate economic case.

A special problem is the choice of material for the pressure vessel. The two main alternatives at present are: (*a*) boiler-quality mild steel, silicon-killed, normalised, and with special acceptance tests, and (*b*) steel of enhanced notch ductility having high manganese-carbon ratio, with grain control by aluminium, and normalised. With the first, special precautions must be taken against brittle fracture, particularly during construction. If the second is adopted to avoid the danger of brittle fracture, some creep strength is sacrificed. To maintain the temperature of the shell below that at which trouble might arise from creep, a double skin can be employed with internal cooling of the outer shell by a controlled flow of cool carbon dioxide gas. Another major problem is the support of the reactor core and the transmission of the load to the foundations, whether by a rocking-column support or by a continuous skirt.

The use of low alloy steels and heat treatment is being actively investigated at present. It is necessary to keep in mind the essential requirement of good weldability under site conditions.

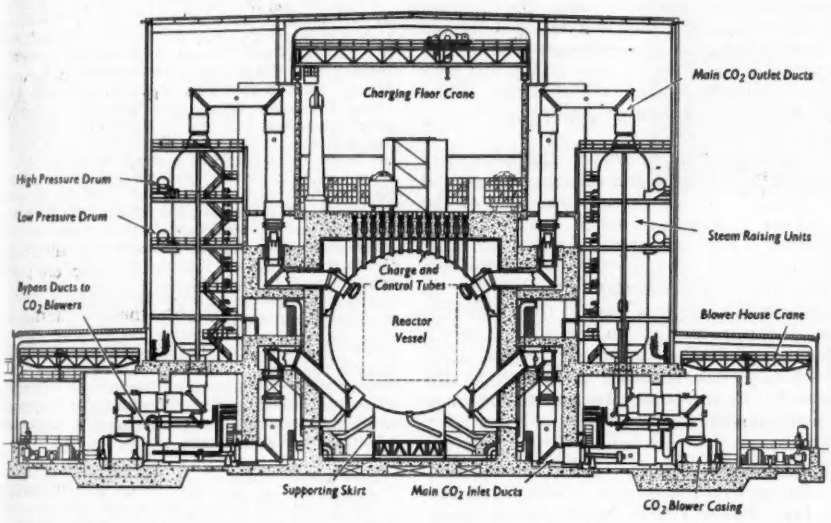
Having noted the development of the "conventional" gas-cooled reactor from Calder Hall to Berkeley, Bradwell, Hunterston, Hinkley Point, and perhaps a little beyond, it is of interest to consider what may be the next move. The limitations of the magnesium alloy canning material have already been mentioned. Beryllium is the favoured alternative at present because of its good nuclear properties, high melting point (1284 deg. Cent.), compatibility with uranium and reasonable mechanical properties. It is however, extremely expensive and difficult to fabricate. In the Calder element, simple substitution of beryllium for magnesium alloy would yield only a small gain because of the limit set by the central uranium temperature with the α—β transition at 660 deg. Cent., and the cost would not be justified.

There are two possibilities for the best use of beryllium: (*a*) a thin section for the uranium, e.g. a tube, a cluster of small-diameter rods, or a group of thin plates in each channel, and (*b*) replacement of uranium metal by its oxide or carbide. Either solution involves slight enrichment of the fuel. A higher average specific heat rating and a higher level of irradiation would be necessary to justify the costs of enrichment and beryllium cans. One is therefore driven to a quite different basic type of gas-cooled reactor.

There is thus the possibility of a series of steps, a kind of discontinuous spectrum with a definite range of development within each band. We are now in the first band, characterised by natural uranium metal rods of approximately 1in diameter, magnesium alloy cans, 8in lattice pitch, &c. Within this first band the output per reactor has already advanced from the 42MW of Calder Hall to the 250MW of the Hinkley Point design. Some further development is possible, and it may be expected that very many power reactors of this kind will be constructed during the next ten years.

The second band of the spectrum is now visible, at least as a distinct possibility, and the general opinion is that this will be characterised by slight enrichment of the fuel, beryllium cans, and either thin metal rods or uranium oxide. A third band would possibly involve the elimination of metal parts from the core and the use of an all-graphite and carbide structure—the so-called high-temperature gas-cooled reactor.

It is perhaps unfortunate that some advocates of the latter have talked in terms of gas temperatures of 800 deg. Cent. and gas turbines. A moderately high temperature reactor, with outlet gas temperatures up to 550 deg. or 600 deg. Cent. at the most, would lead to the prospect of a high-pressure, high-efficiency, reheat steam cycle and a thoroughly reliable plant. Any attempt to produce a large reactor with temperatures of the order of 800 deg. Cent., however, would lead only to frustration, trouble and delay. The existence of a possible next step, or perhaps two steps, in the development of the gas-cooled reactor, is no reason whatever for failing to get on with the immediate practical task of designing and building large power stations of what may now be described as the conventional nuclear type.



Sectional elevation of a reactor building in the nuclear power station to be built at Hinkley Point

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HYDRAULIC ELEVATING TABLE TROLLEY.—A castor-mounted trolley for general industrial use, introduced by Farrow and Jackson, Ltd., 41–42, Prescot Street, London, E.1, has a platform top which is 33in by 21in and can be raised from its lowest setting of 29in to a height of 48in through a hand-operated hydraulic unit. The hydraulic ram is set in the centre of the trolley below the platform, which is guided by telescopic columns at each corner. Loads up to 8 cwt can be raised and, if required, the platform top can be replaced with a roller top to facilitate the transfer of dies or tools to machines, or crates and boxes, between different levels.

INDUSTRIAL CLEANING AND DEGREASING MATERIAL.—A new cleaning material, known as "Pyroclean No. 8," introduced by the Pyrene Company, Ltd., Great West Road, Brentford, Middlesex, is a mild activated alkali powder which can be used in any kind of spray washing machine to clean ferrous or non-ferrous parts of grease or oil. The compound is mixed with water heated to 160 deg. Fah. at a rate of 1 lb per 100 gallons, and is maintained at 130 deg. to 160 deg. Fah. when in use. It is stated that components do not need washing after cleaning with the solution, which imparts a degree of resistance to rust and corrosion for a limited period.

LITERATURE

The Behaviour of Metals at Elevated Temperatures. By MEMBERS OF THE INSTITUTION OF METALLURGISTS. Iliffe and Sons, Ltd., Dorset House, Stamford Street, London, S.E.1. Price 21s.

FOR the past ten years the Institution of Metallurgists has provided refresher courses for its members, and this volume contains the text and illustrations of the lectures given at the refresher course held in 1956. The text of the introductory lecture by Dr. N. P. Allen appears as the first paper, which contains a general description of the engineering properties of metals at high temperatures. Some of these necessarily receive only a brief mention, but the subject of plastic deformation and creep is dealt with more fully. The characteristics of the behaviour of metals under stress at high temperatures and the methods of presenting the results of creep tests are described in such a way as to prepare for a more detailed account of the properties of individual materials in the subsequent lectures. There is an interesting section on the methods employed in developing high-temperature alloys.

In the second paper Mr. G. Meikle, of the Royal Aircraft Establishment, Farnborough, deals with the effect of temperatures up to 450 deg. Cent. These are viewed mainly in relation to their effect on aircraft design and construction. The improved aluminium alloys and the latest magnesium alloys with zirconium and thorium receive most attention, but an account is also given of the behaviour within the specified range of temperature of titanium alloys, an aluminium-iron-nickel bronze and some steels. The third paper by Dr. L. B. Pfeil is on non-ferrous high-temperature materials and deals with alloys containing less than 50 per cent of iron which can be used at temperatures above 500 deg. Cent. Alloys of the platinum group of metals as well as some potentially useful types of alloys are discussed, but more space is given to the outstanding non-ferrous alloys actually in use, i.e. the Nimonic series. Factors which have contributed to the notable development of these alloys are indicated. The paper concludes with an appropriate reminder that materials become more expensive as working temperatures rise, and that efforts to devise effective methods of cooling should not be relaxed. The fourth paper, on high-temperature steels, is by Mr. W. E. Bardgett, who discusses the characteristics of the more established steels, giving references to original sources from which additional data may be obtained. The part played by carbide-forming elements and precipitated carbides in improving the creep behaviour of steels receives considerable attention.

For anyone who attended the refresher course, the book constitutes a useful record of the proceedings. It should also be of interest to a wider circle of readers among those concerned with the use of metals at high temperatures.

Top Link Locomotives. By NORMAN MCKILLOP. Thomas Nelson and Sons, Ltd., 36, Park Street, London, W.1. Price 12s. 6d.

IT is inevitable that the present change-over in motive power on British Railways should bring forth many new books on locomotives. Some are historical and retrospective, some forward looking, and others unashamedly nostalgic. It is difficult at first reading to place the present one. It is written by a retired engine-driver, who was not only a master of his own craft, but who has the gift of writing lucid and entertaining prose. His book takes the unusual form of a series of very informal talks and discussions with senior schoolboys as an audience. He introduces drivers of steam, electric, diesel-electric and gas turbine locomotives, and as an old steam man himself he argues the points for and against the new motive power with men already using it.

It can be said at once that there is no prejudice, no diehard devotion to steam in the tale as it unfolds, and Mr. McKillop comes out as staunch a supporter of the new power as any of the younger men now rising to " top link " status. The professional engineer might, however, tend to lay the book aside on account of its, perhaps, excessive colloquialism, and the general *bonhomie* of the author's style. But for the large number of non-engineers who follow railway matters with a care and scholarship that matches their enthusiasm, Mr. McKillop's book will no doubt prove a very useful reference.

In another way, however, the book may well have an interest and value to professional engineers. At the present time one of the greatest difficulties under which British Railways are labouring is the drift to other industries of so many of the workpeople and staff. By drawing attention, in so graphic and simple a way, to the attractions of a career centred on the more modern forms of railway motive power, Mr. McKillop has rendered a service to the industry he still serves, though no longer as an engineman.

Amplifiers : Design and Construction. Edited by F. J. Camm. George Newnes, Ltd., Tower House, Southampton Street, Strand, W.C.2. Price 17s. 6d.

THIS book covers the design and construction of valve amplifiers for radio, public address systems, gramophone reproduction and tape recording. It contains sufficient theory to provide a basis for the main theme of the book which is the practical side of designing and building amplifiers. Much of the text is based on material previously published in *Practical Wireless* and all the amplifiers dealt with have been tested in the *Practical Wireless* laboratory. The designs described include high fidelity amplifiers for high-power and low-power outputs and inexpensive and high quality amplifiers for gramophones. There is a separate chapter on amplification at very low frequencies using direct coupling between the valves. The text is concise and lucid and the diagrams, almost without exception, are commendably clear, as befits a book which should appeal to the practical man.

Technical Reports

Contribution A L'Etude des Proprietés et des Modes de Décomposition de la Phase Protoxyde de Fer. By R. Collongues. Publications Scientifiques et Techniques du Ministère de l'Air, No. 324. Service de Documentation et d'Information Technique de l'Aéronautique, Magasin C.T.O., 2, Avenue de la Porte-d'Issy, Paris (15e). Price Ffr. 1500.—The protoxyde of iron can be regarded as a typical example of a non-stoichiometric compound as its iron content can vary between 75·8 and 77·7 per cent. The question is whether this represents a true solid solution with a eutectic point, as the region of stability has a point of minimum temperature at 570 deg. Cent. By means of various methods, in particular micrography and X-ray diffraction, it is sought to obtain an answer to these problems. Other kinds of solid mineral solutions studied include FeO–$FeLiO_2$ and Fe_3O_4–Fe_5LiO_8.

The Reduction to Standard Conditions of Take-Off Measurements on Turbo-Jet Aircraft. G. Jackson, B.A., D.I.C., with an Appendix by K. J. Lush, B.Sc., D.I.C. Reports and Memoranda No. 2890. H.M. Stationery Office. Price 6s.—A reduction method intended for routine use is derived whereby the take-off distance required for a turbo-jet aircraft to clear a 50ft screen under a specified set of standard conditions of air temperature and pressure, wind speed, aircraft weight and engine speed can be deduced from the distance measured in an arbitrary set of conditions. The method is basically similar to that used for piston-engined aircraft and the only information required in addition to that which can be observed is a numerical constant for the engine type. The method is shown to be not inconsistent with available experimental data.

Les Séries Chronologiques et la Théorie du Hasard. By M. Kiveliovitch and J. Vialar. Publications Scientifiques et Techniques du Ministère de l'Air, No. N.T. 65. Service de Documentation et d'Information Technique de l'Aéronautique, Magasin C.T.O., 2, Avenue de la Porte-d'Issy, Paris (15e). Price Ffr. 1650.—The authors study the behaviour of a probability generating function in terms of time as the independent variable, using intermediate chronological series. The graphical representation of such a series forms a curve or a polygonal line. Starting from the hypothesis that successive values of the variable are distributed at random, the authors introduce two series for testing significance, one qualitative, the other quantitative. The former tests are based on the topological study of the curve representing the behaviour of the variable with time. The latter consists in determining the probability of the number of points of intersection of the curve or polygonal line with straight lines parallel to the time axis of which the ordinates are the different values which the variable can take. These various tests refer to continuous and discrete variables. Numerous examples of applications to games of chance, the theory of numbers, economics, meteorology, &c., show the practical utility of the tests.

Internal Air-Cooling for Turbine Blades : A General Design Survey. By D. G. Ainley. *Reports and Memoranda No.* 3013. H.M. Stationery Office. Price 11s. 6d. —The degree of cooling that might be achieved in gas-turbine blades with simple internal air cooling is surveyed with a view to pin-pointing the essential requirements for effective cooling with small quantities of cooling air. A shape parameter Z (defined as $(S_c/c)^{1\cdot2}/(A_c/c^2)$) is derived which forms a useful figure of merit for comparing the relative efficiencies of various cooling passage configurations. To secure maximum economy in total cooling air in blades with a given cooling passage configuration, it is desirable that the turbine-blade rows should be designed with high pitch/chord ratios and low relative gas outlet angles (measured from axial direction). These requirements may run counter to those for high turbine-expansion efficiency and in practice some compromise must be sought to give optimum overall efficiency.

It is shown that efficient blade cooling becomes progressively more difficult at lower values of turbine-flow Reynolds numbers, and cooling systems should be designed to give adequate cooling at the lowest operating Reynolds numbers since this represents the most onerous condition.

The potentialities of blades with laminar and turbulent flow in the cooling passages are compared. Although laminar cooling flow might enable better cooling at low Reynolds numbers to be achieved, turbulent cooling flow is generally to be preferred since this : (*a*) permits more consistent cooling over a wide range of Reynolds number in a simple air-cooled engine and (*b*) presents a simpler blade manufacturing problem.

Books Received

Transistor A.F. Amplifiers. By D. D. Jones and R. A. Hilbourne. Iliffe and Sons, Ltd., Dorset House, Stamford Street, London, S.E.1. Price 21s.

Quality Control and Statistical Methods. Second edition. By Edward M. Schrock. Chapman and Hall, Ltd., 37, Essex Street, London, W.C.2. Price 54s.

Cauldon Cement Works

The Blue Circle Group of cement makers has introduced the dry process of cement manufacture to this country with the completion of the Cauldon works near Stoke-on-Trent. One kiln with an annual production of about 200,000 tons has been completed, but provision has been made for an ultimate installation of three kilns. Cauldon works was inaugurated by Mr. Molson, Minister of Works, on September 27.

CEMENT manufacture in this country is traditionally dependent upon the "wet" process, in which a slurry, composed of chalk and clay and with a moisture content of about 40 per cent, is fired in a kiln. Natural materials for this process can be easily won in convenient localities, and the process has been developed to a fine degree of refinement, such that the only major possibility for further economy lies in cutting down coal consumption. With continuing increases in the price of coal, the "dry" process was therefore given consideration, and Cauldon works in Staffordshire, which has just been brought into operation, is the first works in this country to use it. Needless to say, the process is fairly common overseas. The makers consider, however, that recent developments in the dry process have improved the quality of the product. The plant at Cauldon, as it relates especially to the dry process, is largely of German design. Basically the dry process involves raw materials which must themselves be quarried with a low moisture content, generally limestone and shale. They are dried and ground to fine powder, which is blended, and then granulated, to form nodules of a convenient size to be fired. Water must be added at the stage of granulation, and the process is attractive only when the two water contents : (*a*) removed when drying for grinding and (*b*) after granulation, are together substantially less than the 40 per cent of the slurry of the wet process. The water content after granulation is 12 to 14 per cent. The nodules are not fed directly into the rotary kiln, but first of all pass through a chain grate, where a double pass of the hot kiln gases carries out the first stage of heating. This grate contributes to the economy of the firing process by utilising most of the heat in the kiln gases, and allowing a reduction in the length of the kiln (which is a rotary kiln, otherwise just as in the dry process) of the order of 40 per cent.

In discussing the new works, Mr. G. J. Davis, managing director of the A.P.C.M. group, pointed out that the wet process normally used about 25 tons of coal for every 100 tons of cement produced. Cauldon would use only about 15 tons and the power consumption, which had been expected would have been rather higher, was in fact about the same. The cost of the factory, he continued, had been inordinately expensive, something like £3,500,000, but the fuel-saving justified it ; £30,000–£40,000 had been spent for each man employed at Cauldon. Mr. Davis was emphatic that the best-known practice had been followed in the new works. Between £350,000 and £400,000 had been spent, he continued, in meeting the requirements of the amenities of the district. He concluded by pointing out that it was unlikely that any more wet process plants would be built in this country, and the high degree of instrumentation at Cauldon would ensure that all that was possible would be learned from dry process manufacture.

In the ensuing description of Cauldon works, more emphasis is laid on the plant especially connected with the dry process, and operations such as quarrying are touched upon only briefly. For comparison with a modern wet process works we would refer to an article in THE ENGINEER of July 27, 1951, when Shoreham cement works was described.

Quarrying.—Quarrying and crushing of the limestone and shale is carried out at two quarries close to the main works, with the high degree of mechanisation expected for this class of work. Belt conveyors bring the two materials to storage hoppers in the main works. The ratio of limestone to shale consumed is about 4 : 1, and a small percentage of iron oxide (1 to 1½ per cent) is added to make up a deficiency in the natural materials. The full-scale output of the crushing plant at the limestone quarry will be 450 tons per hour, but with the present installation of secondary crushers, 225 tons per hour is the maximum. Limestone is crushed to 1¼in or less, and shale to ¾in. Storage at the works is in the same ratio of 4 : 1, totalling 6000 tons for the limestone.

Production of "Raw Meal."—There are two independent sets of grinding plant, each comprising equipment for feeding, grinding and collection. One set is described in the following notes.

Proportioning is effected by the feeders at the outlets of the storage hoppers, under which a 20in belt conveyor runs. Shale is extracted by an apron feeder having a variable speed drive, and limestone by two vibrating feeders, each of adjustable output between 5 and 35 tons per hour. Iron oxide also is controlled by an apron feeder. The proportioned materials flow to a feed hopper of 34 tons capacity, carried on a load cell, so that the total hopper content can be weighed. Twin vibrating feeders supply material from the hopper to the mill. Adjustable contacts in the gauge of the load cell control the materials feed so that there is always sufficient in the hopper to seal the feed to the mill against the high suction within the mill.

The mill is the crucial element of this section of the plant, and attention should be drawn to its performance. It dries and grinds down to 6 per cent residue on 170 mesh at a rate of 35 to 40 tons per hour. Its construction is indicated in the diagram, and the photograph reproduced gives an idea of its size.

The limestone and shale are pulverised between the three large rollers and the grinding table. Speed of rotation and the spring loading on the rollers depend on the material being crushed. The grinding table, which rotates, is carried on a totally enclosed driving gear. Hot air is introduced through a nozzle ring at the base. Pulverised material is drawn upwards to the centrifugal classifier, which can be set to run at a speed corresponding to the fineness required, and oversized material drops down again for further grinding. A pulverised-fuel-fired furnace is installed to supply the mill with hot air.

The mill stands 28ft high, is 15ft in diameter, and weighs 125 tons. It is driven by a 500 h.p. motor with a 27 h.p. motor for the classifier. The pulverising pressure on the rollers comes from a set of springs which bear on a pressure ring, which in its turn bears on collars on the rollers. The springs are tensioned by wire ropes attached between a spring retaining ring and the foundation of the mill. Motor-driven barring gear is also included.

Fine coal, produced in the kiln coal preparation plant, is blown through approximately 270ft of 9in pipe to fire the furnace, the consumption being given as 2½ per cent standard coal to clinker when grinding limestone at 5 per cent moisture and shale at 20 per cent. The supply of hot air to the mill is automatically regulated in quantity and temperature ; provision is also made for an emergency cold air bleed which automatically opens should an excessive temperature be reached at the mill inlet. The fine meal accepted by the classifier passes to a mechanical "pre-collector" which is positioned immediately prior to an electrostatic precipitator ; the "pre-collector" reduces the initial dust burden of 263 grains per cubic foot to about a fifth of that value. The combined collection unit is designed to handle 44,000 c.f.m. at 160 deg. Fah. and is under suction from a 350 h.p. centrifugal fan, the total resistance of the mill, collector and ducting being about 30in w.g. The combined efficiency of the collector is stated to be 99·9 per cent.

Raw Meal Handling, Blending and Storage.—The raw meal falls into hoppers below the collectors of the two "grinding units," one of which we have just described, and is then conveyed by screw conveyors to a 10in pump which delivers the meal through an 8in pipeline to the top of the blending and storage plant. A continuous sampler is included in this pipeline.

The raw meal blending and storage plant, as illustrated, comprises a pair of welded steel blending silos, 29ft in diameter and 38ft 6in high, supported on grillages on top of a group of four reinforced concrete storage silos, the latter being 29ft in internal diameter and 37ft high. Each blending silo has a nominal capacity of 560 tons, representing the output of the two grinding units

over an eight-hour shift. Thus any initial error in proportioning with the feeders of the raw material hoppers can be adjusted, as the shift progresses, and then by "liquefying" the silo, its contents can be rendered homogeneous. Thus, the blending silos are equipped with compressed air blending equipment. A set of four strain-gauge load cells is incorporated below each blending silo, to give a continuous indication of the weights of the contents.

Meal is delivered to the top of the two blending silos through a motorised valve which can be set to deliver to either silo, or, alternatively, can be put into automatic operation to share the meal between the silos. After blending, the meal is discharged by an airslide system to one or more of the storage silos below; these in turn are discharged as needed to two 10in pumps, each serving an 8in pipeline to the elevated meal hopper in the granulator building.

Granulator Plant.—The 350 tons hopper in the granulator building serves duplicate sets of plant, both of which are kept in use at full output. The two granulators each consist, in effect, of an inclined dish which is rotated; meal and water are introduced to produce pellets the size of which depends on the way in which the dish is inclined and rotated. Water is added to the extent of 12 to 14 per cent.

Some "dry" process works have operated by feeding the powder—the raw meal as we have called it—straight into the kiln. This, however, causes appreciable losses as dust, and generally allows less control or efficiency of heat transfer than the present method, where the pellets from the granulators are first put into the travelling grate described a little further on.

Two illustrations show the granulator plant. The dish itself is carried on a shaft overhung from the combined reduction gear and bearing unit, as is clear from the diagram. Scraper gear comprises a motor-driven arm sweeping the base of the dish, and scrapers on the sides of the dish. Inclination of the dish is varied by the handwheel.

Double-Pass Chain Grate.—Gas flow from the kiln through the double-pass "Lepol" chain grate is indicated in the drawing below, which also shows the general construction of the grate.

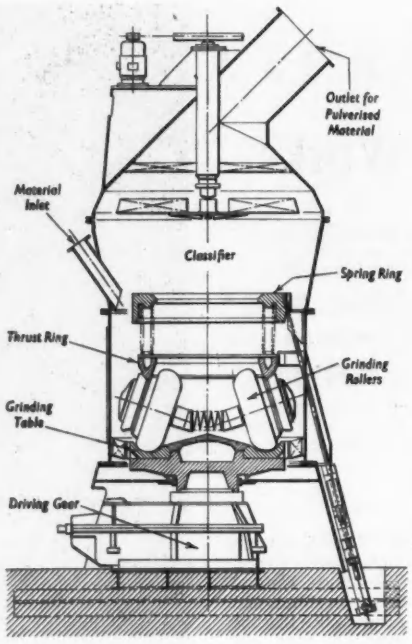


Diagram of mill for grinding cement "meal." Powder is drawn upwards to the centrifugal classifier, which returns coarse material to the mill

Note the dividing baffle, and the cyclones for removing dust from the "hot" or calcining section of the grate. Riddlings from the grate are carried to the kiln, and dust is returned to the granulators by a system of screw and drag chain conveyors and elevators. The kiln gas, at about 1000 deg. Cent., is drawn down through the bed of nodules. It then passes through the cyclones, and is thence carried to the top of the second section of the grate, and drawn down again through the bed of nodules in the second section. It is exhausted to atmosphere at a temperature of about 90 deg. Cent. Moisture is driven off largely in this second pass, when the bed of nodules acts as a dust filter. Nevertheless, an electrostatic precipitator has been installed between the grate exit and the chimney flue. The auxiliary chimney, shown in the drawing above the "hot" section of the grate, is used only when the kiln is being started.

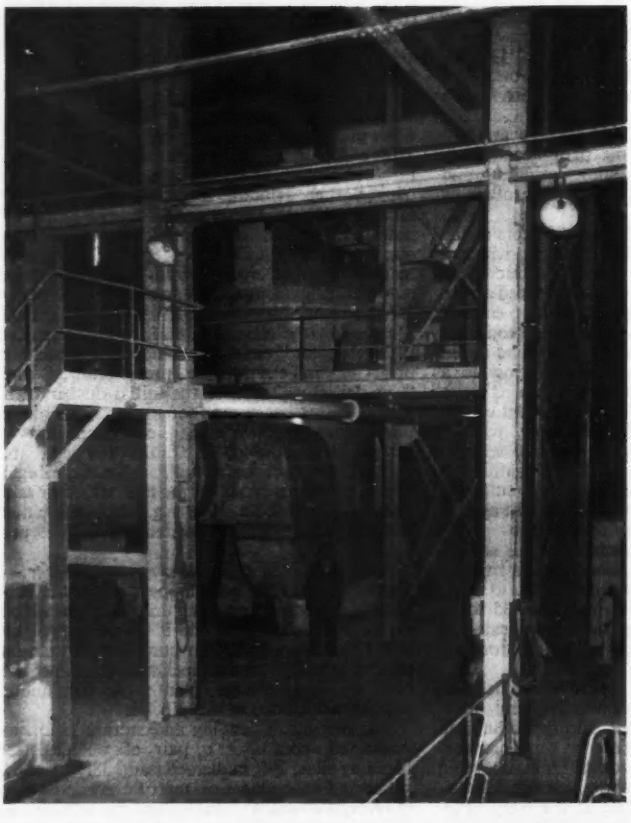
The grate is 13ft wide and 71ft in length between the head and tail shafts. It is driven by a 17 h.p. variable-speed motor through reduction gearing, to the driving sprocket at the kiln end. It is claimed that a saving of 180 to 270 B.Th.U. per pound of clinker is due to this grate, as compared with the single-pass grate which it supersedes; further, the nodules retain their shape right through to the clinker stage.

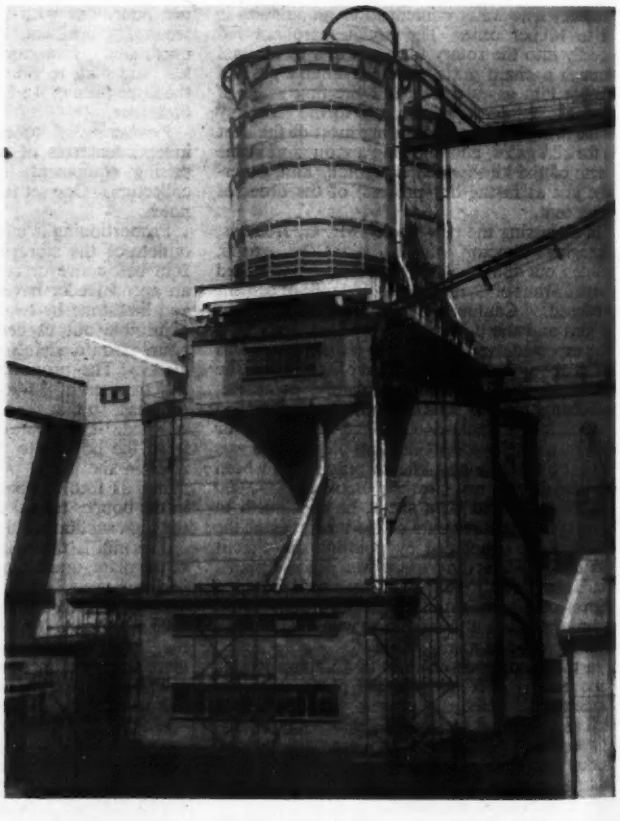
Two induced draught fans are installed to maintain the flow of gas, one at the end of the first pass, after the cyclones, and one between the electrostatic precipitator and the chimney. They are 80in fans, each driven by a 100 h.p. motor. Supply of nodules from the granulators is arranged so that the grate operates with an even layer of material. The electrostatic precipitator is rated to handle 65,000 cubic feet per minute at 250 deg. Fah.; dust from it is discharged to the handling system of the grate.

Kiln and Kiln Cooler.—The kiln is 152ft long with an inside diameter of 12ft 6in; it is of welded construction, and is carried on three tyres, the third tyre incorporating the drive, through gearing, from a 90 h.p. variable-speed motor. The guaranteed output is 500 tons per day (more than 600 tons per day may be achieved), and the standard coal consumption to clinker 14 per cent.

The kiln cooler is also arranged for double-pass circulation, and is a grate cooler incorporating a clinker breaker. It is designed for handling 700 tons of clinker daily (c.f. the kiln output figure) down to a temperature of 170 deg. Fah. The cooler is 7ft wide and 44ft long, with two 65in 70 h.p. fans, one for cold air and one for recirculation.

Clinker and "fines" from the cooler are conveyed by a drag chain conveyor to a fully troughed catenary conveyor discharging to distributing conveyors serving the clinker store,





(Left) The "meal" grinding mill at Cauldon. In the foreground is the hot air duct. The capacity of the mill is 40 tons per hour. (Right) Blending and storage silos for the raw "meal"

where up to 8000 tons of clinker may be kept.

Coal Preparation.—The mill for pulverising coal is similar in general design to the mill already described which grinds the raw meal. The coal mill is smaller, however, and has a static classifier. It is powered by a 100 h.p. motor, and has a rated output of 5½ tons per hour at 12 per cent on 170 mesh.

Hot air is drawn into the mill from a port in the cooler, through a duct which also supplies the kiln's primary air to the "eye" of the firing fan. A cyclone removes clinker dust from this air. Pulverised fuel is drawn up into a filter plant at the top of the building, comprising two six-compartment plants. Each of the twelve compartments is isolated in turn, and cleaned by scavenging the stockings with a reverse flow of heated air; membranes for explosion relief are provided on top of the filter plant. Pulverised fuel is conveyed to two 30-ton hoppers, one for kiln firing and the other for the furnace supplying air to the meal grinding mill.

Final Stages.—The remaining stage in manufacture—adding gypsum and grinding the clinker—is not different from "wet" process works. The two grinding mills—each 45ft long and over 8ft in diameter—each have an output of about 30 tons per hour.

There are four storage silos for cement, giving 5000 tons capacity all told. A twelve-spout packer has been installed for putting cement into bags, and there are facilities for bulk loading. Workshops, stores and testing facilities support the main production installations.

Power Supply.—The estimated maximum demand of the works is 4600kVA, the installation of motors totalling 9500 h.p. Power is taken from the grid at 33kV and transformed to 3·3kV by two 4000kVA transformers. Four substations have been positioned in areas of heavy load, each with h.t. switchgear for motors of 200 h.p. and over, circuit breakers for 750kVA, 3300/415V transformers, and l.t. distribution boards. Sequence control is used to ensure correct starting sequences for machines in a group, and to minimise the consequences of failure of a machine.

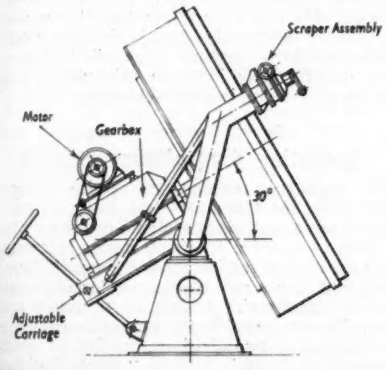


Diagram of dish granulator. The dish itself is overhung on the shaft from the bearing and reduction gear, and thus the inclination of the whole assembly can be varied

Instrumentation.—We mentioned earlier that special attention has been paid at Cauldon to instrumentation. Having now described the main elements of the works, some further notes on the instrumentation may be of interest. The process plant is, in effect, in three parts, namely; (1) raw meal plant; (2) storage and granulator plant; and (3) kiln and calciner.

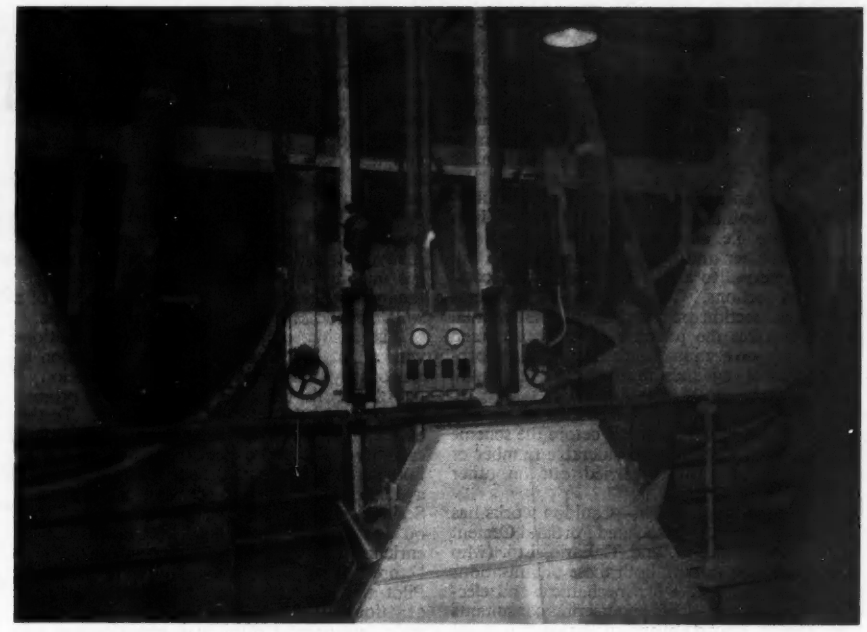
The raw meal control panel is a mimic diagram, the full plant from furnace to outlet stack being depicted. Illuminated arrows show the flow of air and material through the plant and which portion is in operation. All the electrical controls for the plant are mounted on this panel. The instrumentation is relatively simple, consisting of pressure, temperature and flow indication at selected points, miniature instruments being mounted at the appropriate positions on the diagram. All temperature readings are pneumatically transmitted. Two controls are fitted, the first, by bleeding in cold air, safeguards the plant from overheating; the second controls the material level in the grinding mill on the basis of the differential pressure across the mill operating the raw material feeder. Both these controllers are pneumatic.

Each of the blending silos is supported on four load cells and the weight transmitted electrically to the central control panel to facilitate blending of the materials passed to the granulator plant, the control panel of which carries electrical controls in addition to the electrical alarm temperature indicator.

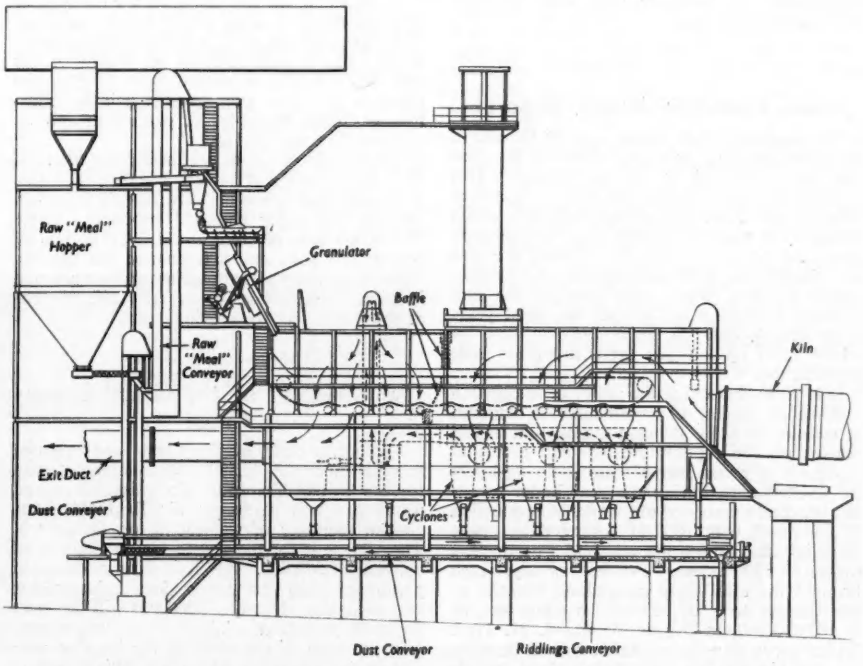
The main instrumentation is, of course, on the kiln and calciner plant. This control panel is part mimic and part graphic, the coal plant section being very similar to the raw meal panel, having very similar measurements on it. Raw and fine coal weights are, however, included.

By following the path of the air and waste gases the measurements and automatic controls fitted to the kiln can be explained. Two air fans supply all the air for combustion and for the coal plant, individual manual control dampers being fitted with pneumatic control on the panel. This air passes through the bed of hot clinker on the grate of the cooler, the speed of which is regulated automatically on the basis of the pressure over the clinker bed at the kiln uptake. Clinker temperatures are also measured and the bleed damper on the cooler is provided with a manual pneumatic control on the panel.

The pressure at the kiln hood is controlled automatically by regulation of the i.d. damper situated between the two sections of the calciner, this again being pneumaticllay operated. Recording of the burning zone temperature is by a "Radiamatic" instrument sighting through the kiln hood. It was considered that after a little while it may be practicable to control the burning zone temperature on the basis of the kiln speed and full equipment has been installed for this to be tried out. The kiln speed and the grate speed with which it must be closely allied are



Dish granulators at Cauldon. Note the hoses for feeding the powder, and the sprays. The hoods are for dust extraction



The chain grate is in two compartments with a double-pass of hot gases from the kiln, as indicated

both recorded by tacho-generators connected to a two-point recorder.

At the kiln exit the waste gases are sampled and taken to a paramagnetic oxygen analyser, the recording instrument on the panel having a pneumatic control which operates the feeder governing the supply of coal to the kiln burner. Combustion is, therefore, under rigid automatic control.

The gases now pass to the calciner, or double-pass grate as we have called it earlier, which is in four sections, i.e. above calciner, below calciner, above preheater and below preheater. The i.d. damper referred to above is between the second and third sections. The pressure and temperature of each section are recorded and a differential converter takes the pressure difference between the two upper sections, and through an appropriate control regulates automatically the louvre damper on the outlet of the plant.

It will be appreciated that there were many unusual problems to be solved before the scheme could be finalised and a considerable number of experiments had to be carried out on other plants.

Design and Construction.—Cauldon works has been designed by the Associated Portland Cement Manufacturers and G. and T. Earle, Ltd. (who will operate the works), both these organisations also being responsible for mechanical and electrical erection. The civil engineering consultants were Messrs. Oscar Faber and Partners, and the main civil engineering contractor was George Wimpey and Co., Ltd.

The principal firms connected with the plant for the "dry" process were: the large mill for meal grinding (and also the coal mill) was designed by Dipl. Ing. Max Berz and supplied by P.H.I. Engineering, Ltd., agents for the Pfeiffer organisation. The granulators and the double-pass Lepol grate were supplied by Polysius, Ltd.

The quadrant blending system for the raw meal, "Airslides" and pumps were supplied by Constantin Engineers, Ltd. The kiln was built by Vickers Armstrong, Ltd.

The instrumentation, which was described in the last section, was designed by G. and T. Earle, Ltd., in conjunction with the main instrumentation contractor, Hartons Installations, Ltd.; the instruments and controls used were obtained from various sources.

Gas Council's Annual Report

THE eighth annual report and statement of accounts, for the year ended March 31 last, has just been published by the Gas Council. This report shows that all of the twelve Area Gas Boards had a net surplus for the year, which totalled just under £3,804,000 on the industry's gross income of £370,600,000. During the year £51,300,000 was spent on additions to or replacements of fixed assets; this brought the sum invested in fixed assets during the eight years since vesting date to some £369 million, of which £130 million has been provided from depreciation.

It is pointed out that the policy of integration and concentration of production in modern economic works is showing steadily increasing returns on the capital invested, and a further reduction in the number of manufacturing works by seventy-seven during the year under review left the total number of 611 works in production as compared with 1050 at vesting date. New plant installed during the year had a production capacity of 102 million cubic feet per day, which brought the total daily gas-making capacity of the industry to 2,535,100 million cubic feet, or 12,100,000 million therms, by March 31, 1957. Rather more than half of the new plant installed was carbonising plant, the remainder being chiefly carburetted water gas plant and oil gasification plant. Plant to the capacity of some 75,000,000 cubic feet per day was scrapped or abandoned, so that the net additional gas-making capacity was 27,000,000 cubic feet per day.

Some 27,668,000 tons of coal were used during the year for gas-making purposes, and of the total gas production 2070 million therms was coal gas; 278 million therms was water gas, and 34,000,000 other gas, whilst 456,700,000 therms was bought from coke ovens and 9,700,000 therms from oil refineries.

Details are given in the report of the research programme for which the Gas Council is responsible This programme aims at improving the efficiency of existing processes of gas manufacture, at developing new processes and new services for the supply of gas, and to attain further efficiency in the utilisation of gas, and the recovery and use of other products of gas making. Two main objectives are being pursued in investigating the possibilities of gasifying types of coal not normally suitable for gas making—the development of a process for the hydrogenation of coal and the designing of a suitable process based upon the Lurgi process.

It is considered that, as a result of investigations with a small pilot plant into the production of gaseous hydrocarbons by the hydrogenation of petroleum oils, the process is sufficiently promising to extend the scale of investigation. To this end a full-scale experimental plant with a daily capacity of 7,500,000 cubic feet is to be erected in the area of the North Western Gas Board, and a 1,000,000 cubic feet per day pilot plant at Solihull. The process for the hydrogenation of oil was originally developed as a means for the enrichment of Lurgi gas, which needs enrichment before it is suitable for distribution as town gas. Pilot and laboratory scale work on coal hydrogenation will proceed simultaneously with large-scale development of oil hydrogenation and will be focused directly on those chemical engineering problems which make the behaviour of coal different from oil.

The search for natural gas in this country is stated not to have been encouraging so far, but it is of interest to note that engineers of the North Thames Gas Board have assisted on trials in the United States in connection with the transport of liquefied methane. As a result of this work it is thought that the possibility of importing a trial cargo of liquefied methane into this country should be considered. Allowing for conversion to a normal calorific value of 500 B.Th.U. a cubic foot, 1 ton of liquefied methane would give 475 therms, compared with 185 therms in the form of gas, coke and tar from 1 ton of coal, and 235 to 310 therms from 1 ton of oil used in gasification plant.

At the end of the year under review the number of gas consumers in the country was just under 12,876,000, of whom 12,126,000 were domestic users. The average income per therm of gas sold was 19·27d. compared with 17·87d. the previous year; the average price paid by industrial gas users was 14·24d. per therm and by commercial users 19·11d.

The net income from products other than gas was £99,300,000, of which £85,000,000 came from coke and breeze and £14,300,000 from tar, benzole and other chemical products. Some 10,243,000 tons of coke and 1,712,000 tons of breeze were sold, and it is pointed out that the mild weather last winter was largely instrumental in reducing coke sales by nearly 1,250,000 tons as compared with the previous year.

Improvement of the Grand Union Canal

ANNOUNCEMENT of the last improvement scheme under the £5,500,000 development plan for the British Transport Commission's inland waterways was made by Sir Reginald Kerr, general manager of waterways, on October 8. The scheme is for the Grand Union Canal, and will cost £1,500,000. It follows the now common pattern of bank protection, lock enlargements and dredging. Nearly £1,000,000 will be spent on bank protection. These works will stretch over 28 miles of the canal in the London area and as far out as Berkhamsted, which section of the Grand Union Canal is classified as a broad waterway. The locks at Brentford will be enlarged, and bank protection carried out chiefly between Brentford and Uxbridge, and between Southall and Harlesden. Sir Reginald made the announcement on the occasion of a display of canal craft and equipment held at Paddington Canal Junction. He claimed that good progress was being made towards the efficient usage of Britain's canals.

Lloyd's Register and the Marine Engineer

ON Tuesday, October 1, Sir Ronald Garrett, this year's president of the Institute of Marine Engineers, gave his presidential address under the title of "Lloyd's Register and the Marine Engineer." After remarking that Lloyd's Register began nearly two centuries ago, he went on to recall that although ships had crossed the Atlantic under steam in 1837, Lloyd's did not appoint an engineer surveyor until 1874. The records of the Society, said the president, did not provide the answer as to the reason for such a time lag, although it had been recognised that attention should be paid to the construction of boilers and machinery. For many years the Society was content to accept a certificate from "some competent master engineer" and it was not until 1874 that the decision was taken to appoint an engineer surveyor. Once the branch was established, continued the president, demand for its services caused a rapid expansion in numbers, such that to-day engineers form over 70 per cent of the technical staff. Sir Ronald said that the Society had, as one of its functions, to encourage pioneering rather than to pioneer, and emphasised that rules can only be formulated after experience has stabilised practice. An engineer surveyor, he pointed out, could become a "ship and engineer" surveyor and as such could be called the general practitioner of the service, while the ship surveyor could be named the surgeon and the headquarters staff likened to Harley Street specialists. The president continued by enumerating some of the qualifications and qualities required of a Lloyd's surveyor, particularly a high sense of responsibility and a high degree of integrity, together with being prepared for his services to be called for at any time. Those who represented the Society abroad, Sir Ronald concluded, carried a particular responsibility in that they could largely influence shipbuilding and marine engineering in those countries.

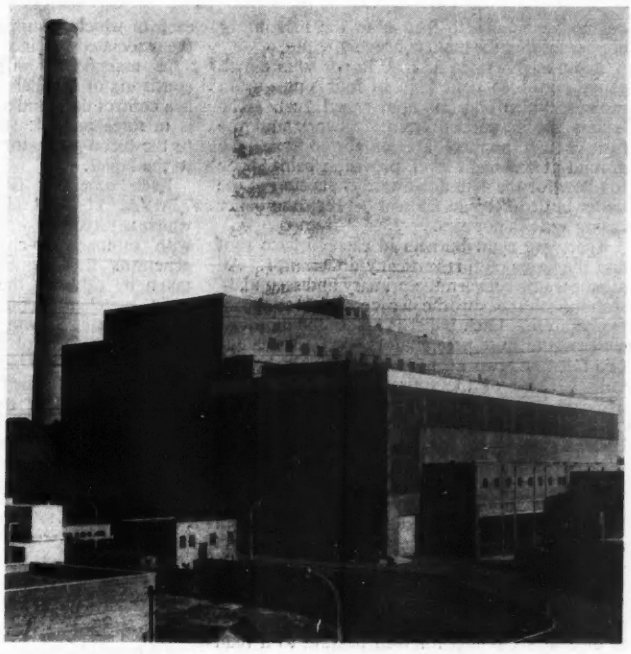
Computing Consultancy Service

A COMPUTING consultancy service is now offered by Short Brothers and Harland, Ltd., who observe that, since a digital computer may be able to invert a 50 by 50 matrix in twenty minutes, such a service opens the possibility of analysing fully a civil engineering structure and thus effecting major savings in its weight and cost. The Analytical Department of the company is organised in two divisions, the first of which operates an English Electric "Deuce" digital computer, and handles all problems involving higher mathematics. The second group, which is responsible for control systems and simulation facilities, is equipped with four Short general purpose analogue computers. This computer, which is distinguished by its ability to both solve problems repetitively and work in real time, was illustrated and described in our issue of September 25, 1953 (page 395); since then there have been developed for it a number of non-linear computing units. These include a multiplier, deriving quarter squares from diode squarers, a continuous function unit which can represent any curve as twenty straight lines and one "steep slope" section, and a discontinuous function unit creating "limiting" or "dead zone" transfer characteristics. A new addition is a low-frequency oscillator able to generate a sine wave down to 0·01 c/s; the mode of operation is to solve the differential equation of a simple harmonic motion, and the output is sufficiently stable to allow computation to continue uninterruptedly for many minutes.

TRACK MAINTENANCE EQUIPMENT.—A licence has been acquired by Beyer Peacock Railway Equipment, Ltd., for the manufacture in this country of the mechanised track maintenance plant of the Railway Maintenance Corporation of the United States. The machines to be manufactured will include the "Spikemaster" for driving four spikes simultaneously; the "Crib" track mounted ballast cleaner; the "Linemaster" track aligning machine; a sixteen-tool ballast tamper; the "Mole" off-track ballast cleaning machine; the "Tiemaster" sleeper changing machine; and a ballast distributing equipment.

Meaford "B" Power Station

Meaford "B" power station, between Stoke-on-Trent and Stafford, was opened on October 4 by H. Wallace Copland, Esq., Lord Lieutenant of the County of Stafford. The output from the four 60MW generating sets in the new station will reinforce that from the four 30MW sets in the "A" station and will be used mainly in the Potteries. Steam for the 60MW sets is supplied on a unit basis by four boilers, each with a maximum rated output of 515,000 lb of steam per hour at 1600 lb per square inch and 1065 deg. Fah. Three of the sets are already commissioned and the fourth is expected to be commissioned this year.



THE two power stations sited at Meaford, about 10 miles south of Stoke-on-Trent, were built primarily to meet the electricity demands of the Potteries. The first station, known as Meaford "A," was projected in 1940 but construction was postponed until after the war and the installation of four generating sets with a capacity of 120MW* came into service in 1948. In the meantime, to meet the growing power demands, plans were made for a second station, Meaford "B," which was to house four 60MW sets, arranged as units with four boilers of 515,000 lb per hour capacity at 1600 lb per square inch and 1065 deg. Fah. The first of these sets was commissioned in November, 1955, the second in October, 1956, the third in June last, and the fourth is due to be commissioned by the end of the year.

The design and construction of the station is being carried out by Messrs. Merz and McLellan and Sir Alexander Gibb and Partners, under the direct supervision of the chief engineer's department of the Central Electricity Authority, London.

The new station is sited just to the south of Meaford "A" and the major part of the station, including the coal store, cooling towers and substation lies between the River Trent on the west and the Trent and Mersey Canal on the east. Immediately beyond the canal is the Manchester-to-London line of British Railways, and beyond that is the ash disposal area for the power station. The coal store and the main station building, which is to the south of it, are flanked on the east by railway sidings.

There is no dividing wall between the boiler and turbine sections of the main building, which is 290ft long by 297ft wide. A cross-section of the building from west to east contains the turbine electrical annexe, turbine room, heater and tank bay; and then a mill and bunker bay, followed by the boiler house proper, an f.d. fan and economiser bay and a boiler house electrical annexe. Beyond the east wall of the building are the electrostatic precipitators, i.d. fans, main flue and a single chimney 400ft high. Oil fuel tanks and pumps for starting up the boilers are installed next to the chimney.

Apart from an emergency cross-over on the feed system there are no interconnections on the steam or water sides of the generating plant, each turbine operating as a unit with its associated boiler. The turbo-generators are installed transversely in the turbine room, part of which can be seen in the accompanying illustration; both boilers and sets are at 65ft centres. There is no separate bay for the boiler feed pumps and they are sited at basement level between the sets in the turbine room. At operating floor level in the heater bay there is a combined control board for each turbine and boiler unit.

A footbridge from the turbine room operating floor level gives access to the station control room which is on the top floor of a four-storey building sited to the west of the main station block. The second floor of this building is a cable chamber for the panels in the control room and the associated relay room. The other floors are occupied by offices. Another building is sited north of the main block and contains the treatment plant for boiler make-up water. To the south of the cooling towers there is a circulating water pump-house. A separate small pump-house on the east bank of the River Trent supplies make-up water to the circulating water system as an alternative to the sewage effluent supplied, for make up, from the Strongford sewage works, Stoke.

To form a level site for the station building, part of a hillside had to be excavated and along three sides of the building there is an embankment. Beyond the electrostatic precipitators this embankment is 22ft high and the railway sidings and tipplers are at this level.

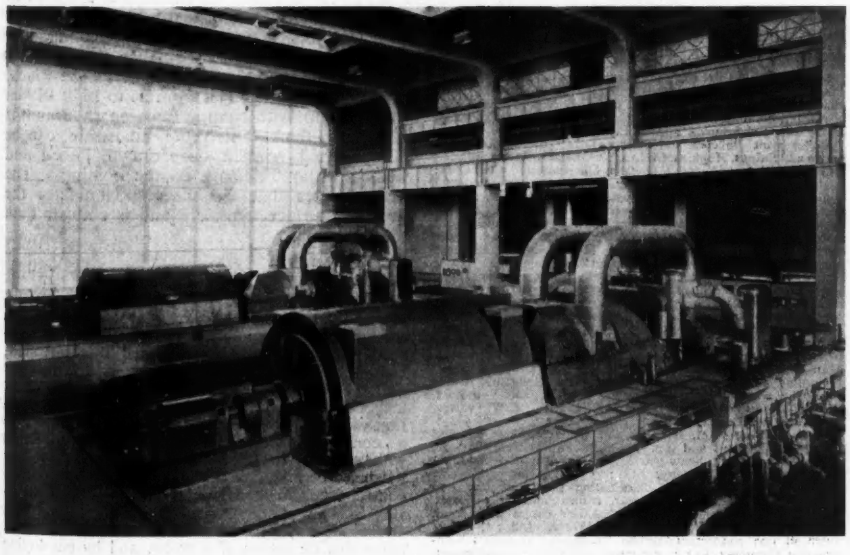
In the boiler house reinforced concrete foundations were laid direct on the rock but, because of the fall in the rock formation, the turbine house area was piled. For similar reasons piling was required for the cooling tower ponds and shells.

With the exception of the wagon tippler control cabin, which (like the rest of the coal-handling plant) is clad with maroon corrugated R.P.M. sheeting, all the auxiliary buildings and the main building are steel-framed, brick-clad, structures. To suit the architectural concept of the station, two shades of external facing brick are used in the main building. Bricks of lighter shade are used for the boiler house, which has the larger superficial area, and bricks of lighter shade for the turbine house and the auxiliary buildings.

Most of the coal is railborne and the sidings that were provided for Meaford "A" station have been enlarged and extended southwards to serve both stations. C.E.A. site locomotives handle all traffic between the tipplers and the sidings for full wagons and empty wagons.

Two side-discharge tipplers serve twin 200-ton-per-hour conveyor lines to the boiler house, a single 400-ton-per-hour conveyor line to the coal store and beyond that to a junction point with the main conveyors. There are twin shuttle belt conveyors covering the whole length of the boiler house over the bunkers. Two 180 h.p. tractor bulldozers are used to distribute coal over the store area from the discharge end of the stocking-

* THE ENGINEER, Vol. 186, 1948, pages 342, 369, 385.



Two of the four 60MW turbo-generators in Meaford "B" power station. Each set forms a unit with its boiler, which has a maximum rating of 515,000 lb of steam per hour at 1600 lb per square inch and 1065 deg. Fah.

out conveyor and to feed it to the reclaiming hopper feeding the main conveyors.

Steam is generated at 1600 lb per square inch gauge and 1065 deg. Fah. in four single-drum radiant boilers burning pulverised fuel. The boilers are suspended from steelwork and the furnace ash hoppers are supported from the ground at basement level, provision being made to allow for the 4¾in downward expansion of the boiler but to keep an air seal between the boiler casing and ash hoppers.

There are eight burners in each furnace roof and the flame path is vertically downwards. An attemperator between the primary and secondary sections of the superheater controls the steam temperature. Each boiler is associated with two electrostatic dust precipitators, two air heaters, two f.d. fans, two i.d. fans and four pulverising mills. Three of the four mills, each with its associated primary air fan, will suffice to serve a boiler, the fourth acting as stand-by. Each boiler is equipped with automatic combustion control equipment to keep the rated steam pressure and temperature at any output.

Ash and dust from the hoppers are carried by a high-pressure water sluicing system through an ash crusher to a sump. Thence the ash and dust are pumped to one of the two settling ponds mentioned above.

Steam is admitted to the turbines at 1500 lb per square inch gauge and 1050 deg. Fah., and is bled at six points for feed heating to a final temperature of 400 deg. Fah. at the maximum load of 60MW. The design value of the condenser vacuum is 28·7 Hg at full load.

Each turbine (see page 533) is a two-cylinder machine having a reversed h.p. cylinder with the steam inlet next to the l.p. cylinder. Two steam chests are provided, cast integral with the h.p. casings—one with the top half casing and the other with the bottom half. The two emergency and stop valves are connected to the upper steam chest. To suit the advanced steam conditions, double casing construction is used in the h.p. cylinder, the inner casing being of austenitic steel ; steam is led into the inner casing through slip joints to allow for differential expansion. The main steam path is inside the inner shell and steam at a maximum pressure of 181 lb per square inch and a temperature of 635 deg. Fah. traverses the space between the inner and outer casings. This construction limits the thermal stresses and distortion on the outer casings and a radiation shield is provided between the two casings to help in achieving this. The exhaust casings are of welded steel construction. Both low-vacuum and low-boiler pressure suppression gear are fitted. The governor and main oil pump are housed in the governor end pedestal and are driven by a hollow quill shaft which ensures accurate meshing of the worm and spur gear train regardless of alignment changes relative to the rotor. The gland sealing system is fully automatic. Electronic supervisory gear is fitted for indicating and recording eccentricity and differential expansion in the h.p. cylinders.

The alternators are hydrogen-cooled, the gas being at a pressure of 0·5 lb per square inch gauge. They are wound for 11·8kV, 50 c/s, three-phase, and are complete with direct-coupled double-unit exciter consisting of main and pilot exciter. The exciters are cooled by air drawn through viscous filters in the foundation block. The stator frame is a gas-tight structure of welded steel and is designed to withstand the maximum pressure developed when the most explosive mixture of air and hydrogen is ignited inside it. The bearings and shaft seals are carried in the end shields. The hydrogen coolers are mounted vertically in the stator frame and are cooled by distilled water which is, in turn, cooled by water in two external coolers. Constant indication of hydrogen purity is provided by intrinsically safe instruments mounted on hydrogen panels. The pressure of hydrogen in the alternator is maintained automatically and an alarm sounds if the pressure falls below a preset value. The shaft seals are fed with oil while the machine is filled with hydrogen and this oil is vacuum treated to remove any absorbed hydrogen and air.

Boiler make-up water is taken from the Staffordshire Potteries Water Board's mains and is treated in a blended base-exchange water treatment plant before being pumped to storage tanks, whence it can be fed to the evaporators, each of which is supplied with steam bled from the associated turbine.

In association with each generating unit, consisting of a boiler and turbo-generator, there is a control desk and a gauge board. The board is in three panels : the left-hand panel relates to the turbo-generator and the other two panels to the boiler.

Each generator is directly connected to a 72MVA, 11·8/141·6kV generator transformer which is forced-oil-water-cooled and is equipped with on-load tap-changing gear. From the generator transformers the station output is taken by cable to the 132kV substation. The main switchgear consists of bulk oil volume circuit breakers with a rupturing capacity of 2500MVA. Control of these circuit breakers is exercised from the new control room which is primarily for Meaford " B " but also serves as a master control for the two stations now that certain functions have been transferred to it from the " A " station control room.

Particulars of some of the main auxiliary drives are tabulated herewith :

F.D. fans, 2 per boiler :	
Capacity at 90 deg. Fah., each	95,000 cubic feet per minute
Motor	228 h.p.
	730 r.p.m.
	3·3kV
I.D. fans, 2 per boiler :	
Capacity at 290 deg. Fah., each	150,000 cubic feet per minute
Motor, two speed	608/345 h.p.
	730/585 r.p.m.
	3·3kV
Boiler feed pumps, one per boiler with one stand-by per pair :	
Discharge at 2000 lb per square inch	567,000 lb per hour
Motor	2000 h.p.
	3000 r.p.m.
	3·3kV
Circulating water pumps (four horizontal shaft sets) :	
Capacity, against 55ft head, each	2,400,000 gallons per hour
Motor	950 h.p.
	493 r.p.m.
	3·3kV

Electrical supplies for the station auxiliaries are taken from two 10,000kVA station transformers and from the 6000kVA unit transformer which is directly connected to each generator. Supplies for the essential auxiliaries concerned with each turbo-generator and boiler operating as a unit are taken from the associated unit transformer. During starting up these and other auxiliary supplies are taken at 3·3kV from the station transformers, each of which is capable of handling the normal station load.

Supplies for the smaller auxiliaries are at 415V ; for essential unit auxiliaries the supply comes from a unit auxiliary transformer which is fed at 3·3kV from the associated unit switchboard. General station auxiliaries, including coal handling and ash handling, are supplied at 415V from duplicate transformers fed from the 3·3kV system of the station transformers. Air-break circuit breakers are used on all the 3·3kV and 415V switchgear. the rated rupturing capacities being 150MVA and 15MVA, respectively.

Contractors

The main contractors and some of the principal sub-contractors for Meaford " B " power station are listed below.

Site excavation, roads, foundations and railway sidings, superstructures and ash ponds, G. Percy Trentham, Ltd. ; brick chimney, P. C. Richardson and Co. (Middlesbrough), Ltd. ; steel frame buildings, Cleveland Bridge and Engineering Company, Ltd. ; ash pond dumpers, Fodens, Ltd. ;

Boiler plant, Babcock and Wilcox, Ltd. ; boiler mountings, valves and fittings, Hopkinsons, Ltd. ; air heaters, James Howden and Co., Ltd. ; I.D. and F.D. fans, Davidson and Co., Ltd. ; coal weighers, R. Simon and Son, Ltd. ; soot blower control equipment, British Thomson-Houston Company, Ltd. ; ash hoppers, Karrena Furnace Engineering Company, Ltd. ; dust extracting plant, Sturtevant Engineering Company, Ltd. ; instrument and control panels, Electroflo Meters, Ltd. ; steam temperature control equipment, Bailey Meters, Ltd. ; boiler and pipework insulation, Newalls Insulation Company, Ltd.

Turbo-generators, British Thomson-Houston Company, Ltd. ; instrument and control panels, Electroflo Meters, Ltd. ; automatic voltage regulators and turbine supervisory equipment, Metropolitan-Vickers Electrical Company, Ltd. ; feed heating plant and condensing plant, Hick Hargreaves and Co., Ltd. ; turbine-house crane, Sir William Arrol and Co., Ltd. ; motors, British Thomson-Houston Company, Ltd. ; boiler feed pumps, Mather and Platt, Ltd.

Cooling towers, Davenport Engineering Company, Ltd. ; circulating water pumps, W. H. Allen and Co., Ltd. ; motors, British Thomson-Houston Company, Ltd. ; C.W. valves, Alley and MacLellan, Ltd.

Coal handling plant, Babcock and Wilcox, Ltd. ; ash and dust handling plant and h.p. pipework, Babcock and Wilcox, Ltd. ; l.p. pipework, Shaw Petrie, Ltd., and Brightside Foundry and Engineering Company, Ltd. ; water treatment plant, Permutit Company, Ltd. ; chlorinating plant, Wallace and Tiernan, Ltd. ; 132kV switchgear, control and relay panels, General Electric Company, Ltd. ; 132kV cables and trunk multicores, Pirelli General Cable Works, Ltd. ; 132kV overhead line connectors, British Insulated Callender's Construction Company, Ltd. ; generator and station transformers, British Thomson-Houston Company, Ltd. ; auxiliary transformers, Brush Electrical Engineering Company, Ltd. ; auxiliary switchgear, A. Reyrolle and Co., Ltd. ; cabling, W. T. Henley's Telegraph Works Company, Ltd.

Expanded Polystyrene

A FORM of expanded polystyrene intended for insulation, stabilisation and provision of buoyancy is now available from Expanded Plastics, Ltd., 675, Mitcham Road, Croydon, Surrey. This material, " Polyzote," expands at temperatures above 140 deg. Fah., and can, therefore, conveniently be processed in or above boiling water, or formed in place using steam injection. The material is originally in the form of granules, which are pre-expanded to a density between 2 lb and 6 lb per cubic foot by heating for a few minutes and then stored for more than twelve hours but less than ten days. The expanded granules are then packed in a mould defining the finished shape and again heated, when they expand further and sinter together into a mass of closed cells. The density of the final moulding may be as low as 1 lb per cubic foot.

The physical properties of " Polyzote " are not as favourable as those of an expanded rubber such as " Onazote," but the material is cheaper and suitable for expendable packings or for house insulation. The thermal conductivity is 0·22 B.Th.U. per square foot per hour per deg. Fah. per inch at a mean temperature of 30 deg. Fah., the compression strength 15 lb per square inch, and the tensile strength 18 lb per square inch, all at a density of 1·25 lb per cubic foot. The maker supplies a material of this quality in standard boards 2in or 1½in thick, which can be slotted for application to cylindrical or domed surfaces. These boards are easily worked, and can conveniently be cut by a hot wire dissipating about 8W per inch. The material has a smooth matt appearance, white or tinted, but various finishes, including aluminium paints, can be applied.

These boards are also suitable cores for structural sandwiches, there being a number of adhesives to attach wood, plastic or metal skins. For buoyancy units in place of metal tanks, the polystyrene can be used in board form or in a shape suiting the space available. Water absorption is only 3·2 per cent by volume after six weeks' total immersion.

Plastics-Coated Steel Sheet

THE introduction of a P.V.C.-coated steel sheeting is announced by John Summers and Sons, Ltd., Shotton, Chester. Named " Stelvetite," the material consists of cold-reduced strip with what is described as " a specially formulated P.V.C. coating " on one side. The reverse side of the sheet, it is stated, can have either a bonderised steel or electro-zinc-coated surface. Claimed to have been developed exclusively by John Summers and Sons, Ltd., and B.X. Plastics, Ltd., in conjunction, the material is reported to be a good electrical insulator, highly resistant to acids, alkalis, greases, detergents, humidity, abrasion, &c., stable at higher temperatures than P.V.C. alone, and pleasant to the touch. Available in steel gauges from 26 to 16 (0·0196in to 0·0625in), with coating fourteen thousandths of an inch thick, " Stelvetite," it is said, can be bent, formed, seamed, deep drawn, joined and welded without damage to the coating. The maker states that the sheeting eliminates the need for surface treatment and is cheaper than stainless steel.

CONSTANT-SPEED PNEUMATIC-CYLINDER CONTROL —A new control unit, known as the " Hydrocheck," which has been developed by Martonair, Ltd., Parkshot, Richmond, Surrey, is designed for use on equipment where a constant speed is required independent of load variations. It is used in conjunction with a conventional pneumatic cylinder to give a constant piston-rod speed in one direction with a free return. Its action is similar to that induced by a hydraulic dashpot and the characteristic control is maintained independent of a load up to 1000 lb. These units are made in four models with strokes of 3in, 6in, 9in and 12in. The flow rate is adjustable by means of a screw, and by employing an extension stud a fast approach can be arranged before the restricted movement is imparted by a " Hydrocheck."

Two-Speed Torque Converter Transmission

A TRANSMISSION consisting of a torque converter and a two-speed and reverse gearbox is now being put into production by Brockhouse Engineering, Ltd., to take the place of the clutch and six-forward, two-reverse ratio transmission normally fitted to the Fordson " Major " tractor. While the standard transmission provides the highest efficiency for towing duties, it demands much effort in manipulation of clutch and gear lever from the operator of a mechanical shovel or similar equipment, many of which are driven by the Ford power unit. The alternative transmission has a " hot shift " allowing any gear to be engaged regardless of engine or vehicle speed, while the incorporation of a torque converter means that the extra thrust needed to crowd material into a bucket is generated without intervention by the driver.

As the accompanying drawing shows, the converter is of the class described as a turbo-transmitter, the stator being mounted on a free-wheel so that when the output speed is too high for torque multiplication the unit behaves as a fluid coupling : the torque multiplication at stall is 3·1. The gearing takes the form of two epicyclic trains, generating ratios of 1 : 1 and 2·175 : 1 forward and 2 : 1 in reverse.

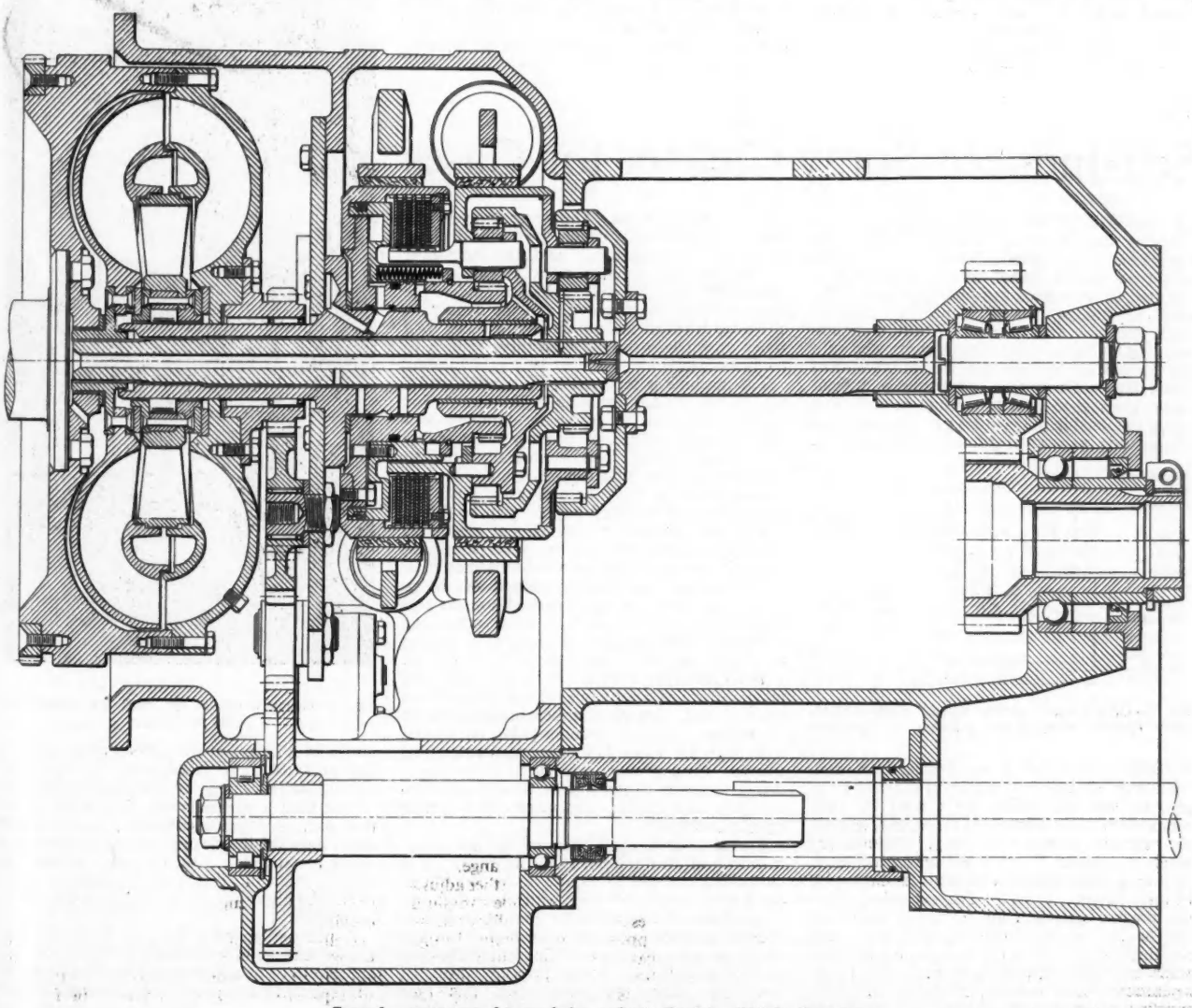
The rotor drives the sun wheel of the rear epicyclic and the annulus of the front epicyclic ; the simplest operating condition is reverse, where the rear planet carrier is anchored by the band brake and the rear annulus revolves at one-half input speed. In low forward, the sun wheel of the front epicyclic is locked by the front brake ; both epicycles are running, the front one feeding a relatively slight reduction into the planet carrier of the rear to achieve an overall reduction of 2·175. High forward is engaged by a clutch which locks the sun wheel and planet carrier of the forward cluster together, providing direct drive through the whole gearbox.

The efficiency of this epicyclic gear, when in low forward or reverse, is effectively 95 per cent, whereas the final drive efficiency is only 90 per cent. This being so, it is noteworthy that an efficiency of 75 per cent is obtained above half speed in high forward, the converter efficiency at the coupling point being 87 per cent. The performance of the coupling lies within ±3 per cent of design figures on production runs, we are assured.

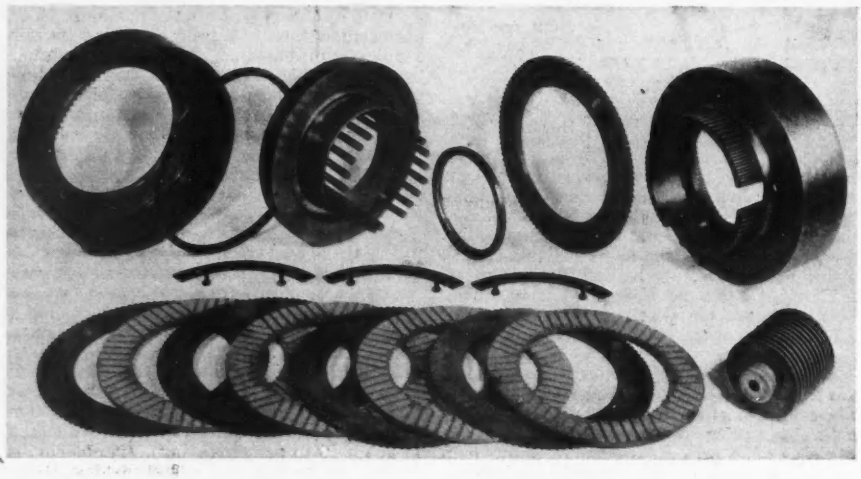
The detail design is not without interest, since plate clutches are less usual than band brakes in oil-operated transmissions in this country : this is the first production transmission from this maker to embody such a clutch. The plates driving at their outer edges are steel, but the remainder are moulded in one piece from Don friction material. On pilot production transmissions the driving teeth are cut into the friction disc by the gearbox manufacturers, but it is anticipated that production quantities will have the teeth included in the original moulding. The main components of the hydrodynamic converter are die cast in aluminium, the cores being of sand bound with plastic as in the shell moulding technique. As mentioned above, a highly consistent performance is afforded by production lots of parts. These components are balanced individually before assembly, so that they can be reassembled in any attitude.

The transmission is energised and lubricated by hydraulic fluid of S.A.E. 10 viscosity. A Hobourn Eaton pump can be seen driven from one of the idlers in the " live " power take-off ; while it is above oil level, it is found that even on a worn pump self-priming is invariable. The filter is an Air-Maze ; consisting as it does of a concertina-shaped gauze, this strainer has such a low pressure drop that it is possible to use it to protect the pump by mounting it in the suction pipe. A pressure of 70 lb per square inch is maintained in the servo system, while a restriction in the supply to the converter causes that to run at about 50 lb per square inch. No cooling is found to be necessary on a transmission of these proportions ; O-rings in the hottest parts are, however, of silicone rubber. All these accessories and the control valve, a simple spool with five positions (high–neutral–low–neutral–reverse) are carried on a side cover cast in light alloy.

Behind the gearbox proper there is a casing which serves to render the assembly interchangeable with the normal transmission. It will be noticed that the shaft spanning this casing has no bearings : at the forward end it rides freely on the output planets, thus ensuring that the load is shared equally between them, and at the rear it is located in the splined hub of a straight-toothed pinion. It is constrained axially between the oil feed jet in the end of the converter shaft



General arrangement of transmission to fit the Fordson " Major " tractor



The clutch dismantled : notice that alternate plates are mouldings of friction material, grooved across the faces. Right, foreground, is the convoluted gauze suction filter

and a circlip clasping the splines. Three different ratios are made for this secondary reduction train : the highest gear gives 14·6 m.p.h. at 1700 r.p.m. In the case of the highest ratio, the pinion is too small to house taper roller bearings and runs on Torrington caged needles ; endwise location of the pinion is then provided between a plain thrust washer and the circlip on the shaft. In this case also the loads on the overhung output gear are so high that the single row, deep groove ball bearing is supplemented by a parallel roller bearing. The output gear accepts the normal tractor drive shaft, and in fact the seal outside and the cap inside it are Ford parts.

The transmission is to be supplied complete to equipment manufacturers, who will attach it to the Fordson power unit in place of a dummy gearbox, although in due course a certain number of units may have these transmissions installed on the production line. Threads are Unified throughout, and being adaptable to the " Major," the converter will also fit Perkins " L.4 " and " P.6 " engines. Several units have already undergone service trials and have proved successful in, for instance, moving ore in the holds of ships, where plate clutches had only a limited life. On a job of loading vehicles with mineral, a converter-equipped shovel not only reduced the cycle time, but extended the endurance of the operator from one hour to a normal day. Production transmissions are expected to become available next spring.

Self-Induced-Spray Cleaner for Gases

A RANGE of self-induced-spray cleaners is being introduced by Dallow Lambert and Co., Ltd., Thurmaston, Leicester. Extensive prototype testing under service conditions is reported to have given satisfactory results. The usual advantages of wet cleaners are claimed (high efficiency, safe disposal of dust, compactness, &c.), and the equipment is contrasted with the less efficient cyclone and the less consistent fabric filter. Dusts that are normally difficult to wet are said to yield to the intense scrubbing action obtained in the new design. The principle of operation is shown diagrammatically in Fig. 1.

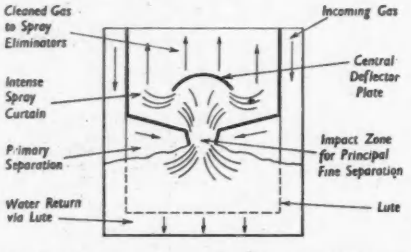


Fig. 1—Diagrammatic section through a self-induced-spray cleaner, showing the principle of operation

Particles are collected by two mechanisms, first, the abrupt change in direction of the dust-laden gas, so that the solids are carried by their momentum on to irrigated surfaces, and, second, the vigorous mixing with spray. Polluted gas enters the cleaner through vertical downcomers, as shown in the diagram. Dust is then removed in three stages : (i) at the first deflection of the gas streams over the main surface of the water, the heavier particles entering the latter and remaining in it ; (ii) in the so-called impact zone where the sharp changes in direction lead to the separation of finer particles, and also to an intimate mingling of water and gas, and (iii) under the central deflector plate. The water spray in the cleaned gas stream is caught by inclined plates known as " eliminators," and the carry-over to the fan and exhaust stack is said to be negligible. The induced turbulence renders the inner chamber self-cleaning, and the deposition of sludge is stated to be insignificant there. All water drawn into the inner chamber returns to the bottom tank.

The machine is reported to be available with any of four sludge-removing equipments. For high dust burdens an automatic drag-link conveyor is recommended, particularly where operation is continuous. This is normally fitted to units passing 6000 cubic feet per minute or more. For severe duty, e.g. where abrasive dusts are encountered, an elevated hopper may be fitted: this is designed to facilitate manual clearance. Where the dust load is light small units permitting manual clearance from the a flat-bottomed tank are available. The fourth method of sludge disposal involves the use of conical hoppers and drain valves, and is said to show advantage where the discharge can be taken to a settling pond thickener, or to a continuous drain to waste.

The cleaners are made of welded mild steel plate and rolled steel angle. Easy access doors are provided. Internal surfaces usually receive three coats of hard bituminous paint, but special treatments are available for the more severe conditions. The conveyor, where fitted, is electrically driven at about 2ft per minute through a reduction gear and chain ; a slipping clutch guards against overload.

Correct water levels are maintained automatically in all the cleaners in this range. The controllers are said to require no further adjustment after installation, even with wide variations in gas rate. As a result of the controlling action, roughly the same pressure drop occurs through the cleaner at all gas rates. Collecting efficiency stays constant also. The pressure drop, it has been stated, is lower with this type of self-induced spray than with any other.

The manufacturer claims to be the only one specialising entirely in dust control, and takes particular pride in the methods devised for the assessment of users' problems. The physical and chemical properties of the dust to be collected are first determined in the company's laboratory. Where applications of the wet cleaner are in question, special attention is paid to the behaviour in water. If foaming or retarded settling is

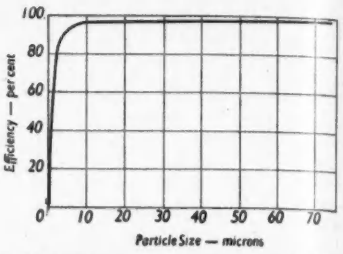


Fig. 2—Manufacturer's example of a grade/efficiency curve for a wet gas cleaner. Efficiency is measured on a weight basis

suspected, plant conditions are simulated in a standard wet cleaner maintained for just such tests. The anticipated collecting efficiency is calculated on the basis of a size analysis of the dust sample (which must, of course, be truly representative). The sample is sieved down to 200 mesh (76μ), and the portion below this size is analysed in a sedimentation cell (developed from the Andreason apparatus), which is reported to resolve down to 2·2μ. Less accurate air elutriation methods are resorted to when the

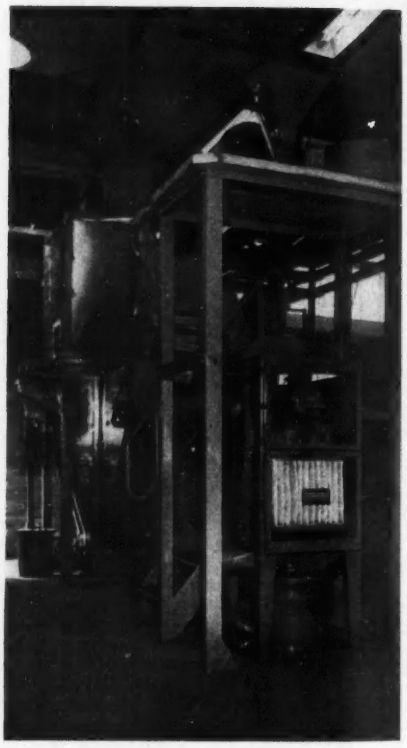


Fig. 3—Manufacturer's rig used to demonstrate wet gas cleaner

dust is of a kind that will not settle in liquid. A size analysis curve is obtained in which the cumulative percentage of dust particles that are of less than a particular size is plotted against that size. A " grade efficiency " curve is then determined for the cleaner operating on the dust under investigation : such a curve is shown in Fig. 2. With this data the manufacturer claims to achieve high accuracy in predicting the collecting efficiency.

A photograph of a demonstration model of the wet cleaner is reproduced in Fig. 3. Models are said to be available in thirteen standard sizes with capacities from 2000 to 48,000 cubic feet per minute.

Industrial and Labour Notes

Investment in Building

At the official opening of the Cauldon cement works (see page 529), on September 27, the Minister of Works, Mr. Hugh Molson, spoke about the effect of the Government's financial policy on building and civil engineering and on the building materials industry. He recalled that, last year, £1450 million of the country's capital investment went into new construction and about £650 million into maintenance work. The Government believed that one main cause of rising internal prices and of the past weakness of the pound sterling abroad had been that we were trying to do too much in too short a time. It was natural, therefore, Mr. Molson said, that a limit on construction should be regarded as a necessary part of the plan to check the rise in prices and to maintain the external value of sterling.

Mr. Molson went on to say that the £2100 million spent last year on construction work was shared by private enterprise, local authorities, the nationalised industries and by the Government itself. So far as the Ministry of Works was concerned, he said he was re-examining its building programme at home and abroad, which amounted to £51,000,000 a year, to see what cuts could be made. The building industry, and therefore the building materials industries, would feel the effect of those new measures and, Mr. Molson remarked, it was intended that they should. Mr. Molson went on to refer to the fixed price tender which was introduced last April " in an attempt to interrupt the vicious spiral of increasing costs and wages in the building industry." He pointed out that the contractor was now expected to carry the risk of increased cost of materials or labour in jobs that were completely pre-planned and likely to be completed within two years. The reduction in jobs which would result from the 7 per cent Bank rate and from other measures announced by the Chancellor of the Exchequer would obviously intensify the competition among civil engineering contractors and builders and would consequently have its effect upon the manufacturers of building materials. Mr. Molson expressed his hope that that would keep down the cost of building, but added that the output need not decline much at all if there was the necessary increase in efficiency from management and in effort from labour. The progress and prosperity of the country, he said, obviously depended on new building and its prices ; competition and co-operation both had their parts to play.

Petroleum Equipment for Canada

The Economic, Technical and Goodwill mission to Canada, which was sponsored by the Council of British Manufacturers of Petroleum Equipment, has now published its report. This report estimates the current annual rate of expenditure of Canadian oil and petro-chemical industries at 750 million dollars and states that in refining and processing only 7 per cent of the equipment is bought from the United Kingdom. Long delivery periods and lack of service are given as the main reasons for the low volume of sales. To enter the Canadian market the report recommends that the maintenance of adequate stocks, the presence of technical representatives and the provision of technical sales literature are essential.

The report goes on to outline trade development in Canada and gives details of the oil industry, both as regards production and purchasing methods, and adds various " selling pointers " which include literature, spares, service, standards, climatic requirements and tariffs. A number of specialist reports contain information concerning particular items of equipment and there is a summary of the sources of information, together with a list of companies visited and the personnel interviewed. Tabular statements in the report record data about the oilfields in Alberta, Saskatchewan and Manitoba, and a geographical survey gives particulars of the provinces and their principal industries and the value of the mineral production.

Trade Mission from British Columbia

A trade mission from British Columbia arrived in this country last week. It is headed by Mr. Robert W. Bonner, Q.C., Attorney-General and Minister of Industrial Development for the Province, and its members are to visit various industrial centres in this country and on the Continent. The mission is the fifth of its kind in recent years, its main purpose being, of course, to encourage a better pattern of trade on reciprocal lines. In particular, the mission is anxious to enlist further participation of British capital and enterprise in the industrial expansion which is now taking place throughout British Columbia. At a press conference last week, Mr. Bonner said that the value of projects at present in hand in the province now exceeded 1000 million dollars.

Industrial Opportunities in Durham

The Durham County Council has just issued an illustrated brochure by which it is intended to make more widely known the possibilities and advantages which the county can offer for expanding industry. The brochure says that the total working population of County Durham is 587,000, and that there is a surplus of labour. Many young people now leave the county to seek work, and there is a large untapped source of female labour. Both these groups, it is urged, could be drawn into employment if it was available locally. The County Council is anxious to stop the migration of Durham people and it is convinced that many of the people would not leave if they could find suitable jobs. New industry has come to the county but, the brochure says, the rate at which it has come has not increased in the way it has in the Home Counties.

Copies of the brochure are available from the Durham County Council's Industrial Bureau, 10, Church Street, Durham.

Smoke Control Orders

The first confirmation of an order under the Clean Air Act, setting up a smoke control area, has been given by Mr. Henry Brooke, Minister of Housing and Local Government. It covers 100 acres in the centre of Liverpool. The area runs from Georges Pierhead to Hatton Garden and Manchester Street. It is bounded on the north by Chapel Street and Tithebarn Street, and on the south by James Street, Lord Street and Whitechapel. The area comprises shops and offices, with a few houses and some Corporation buildings. There were no objections to the Order, which will come into operation on April 1, 1958. It will be recalled that under the Clean Air Act, local authorities are empowered to declare smoke control areas by means of orders confirmed by the Minister of Housing and Local Government. These are areas in which it is an offence to emit smoke from a chimney. An order may apply to all the buildings in the area or may be limited to certain buildings or it may exempt specified buildings or specified fireplaces from its operation.

The Minister has also confirmed three further smokeless zone orders under the Manchester Corporation Act, 1946. These smokeless zones are in Miles Platting, Ancoats and Harpurhey, and in each case the zones cover areas which are to be cleared and redeveloped for housing. Clearance will be completed before the orders come into operation and the zones will therefore affect only the new houses erected on each site. The Miles Platting Order comes into operation on April 1, 1958, the Ancoats Order on July 1, 1958, and the Harpurhey Order on November 1, 1958. The confirmation of these three orders brings the number of smokeless zones in Manchester to fourteen.

Overseas Exhibitions

Early in June the Scottish Council of the Federation of British Industries arranged a conference on " Exports and Overseas Sales Promotion." It was attended by representatives of Scottish industry and by delegates from the Board of Trade, the Scottish banks and other commercial organisations. A full report of the proceedings has now been published by the Federation of British Industries, 21, Tothill Street, London, S.W.1 (price 1s. 6d.).

One of the conference sessions was devoted to the subject of overseas exhibitions and trade fairs, and the report now published presents some useful guidance about participation in these events. It is explained that the F.B.I. is doing what it can to ration demands from overseas for British Fairs and is encouraging participation in well-established international trade fairs where they exist. In heavy goods, in particular, the report says, it is desirable that an exhibition should be organised on a trade section basis. Costs may be reduced by organising a composite exhibit, which is something trade associations are often able to do well.

The report emphasises the importance of maintaining a high standard of organisation and display at exhibitions. It says " it is often a waste of money for a firm to organise and pay for an attractive stand and invest in an exhibition when the general standard is poor." At the conference there was some discussion about the extent of Government participation in exhibitions, the general view being that where it is considered that firms should exhibit for prestige reasons, with no immediate prospects of business, some form of Government subsidy is not unreasonable. It was realised, however, that in the case of industrial goods results are not seen immediately. Not often are the goods sold off the stand ; the results come later when tenders are out for a particular job or when a development scheme is launched. Then, the report says, particular firms are remembered from their exhibits at past fairs.

CERN 600 MeV Synchro-Cyclotron

After just over two years of construction at the CERN laboratory centre at Meyrin, near Geneva, the 600 MeV synchro-cyclotron recently began test runs at peak output energy. The internal current during the first runs was about 0·1μA ; it is expected that the current will later be increased. The machine is the first of two high-energy particle accelerators to be built for the European Organisation for Nuclear Research (CERN), the other being the giant 25 GeV proton synchrotron, which, when completed in 1960, will be able to accelerate protons to energies of 25,000 MeV. The CERN synchro-cyclotron is the third largest of its kind in the world. Slightly bigger machines are in operation at the Radiation Laboratory, University of California, Berkeley, U.S.A., and at the Joint Institute for Nuclear Research at Dubno, near Moscow.

THE large synchro-cyclotron, which has been under construction at the CERN research laboratories at Meyrin, near Geneva, has now come into operation. This machine is designed for an energy of 600 MeV, and it is hoped that an average current strength of 0·2μA will eventually be obtained. Since it became clear during the construction of the accelerator that a fairly large number of the experiments for which it would be suitable had already been carried out, it was decided to concentrate the research programme mostly on work requiring a high degree of accuracy. Experiments will involve protons, neutron, polarised proton, pion and muon beams. During the current year, the Division's staff is being increased from ten physicists and three fellows to twenty physicists and twenty-seven fellows. As CERN is an organisation in which several European countries jointly participate, research teams from the member States should have the opportunity of using the accelerators—a second much larger machine, the 25 GeV proton synchrotron will be completed in 1960—for carrying out their own experiments. The problem of co-ordinating the work of individual teams has been thoroughly studied, and recommendations have been made to the Scientific Policy Committee.

The principal data of the machine may be seen from Table I. The proton beam circulating inside the synchro-cyclotron has been designed to have a peak energy of 600 MeV, as has been mentioned. A proton beam extraction system similar to that used in the Liverpool and Chicago accelerators is to give a concentrated beam of high intensity and will define energy outside the machine in order to facilitate experiments. Expected values are 10^9 protons per pulse and 55 pulses per second. Internally produced neutron beams in seven steps of 70 MeV each, rising from 110 to 600 MeV, will be available in an array of parallel channels cut through the shielding wall. A two-channel array is to be used for the extraction of negative pions. By means of proper adjustment of the focusing and deflecting devices it is expected to obtain a continuous spectrum from 100 to 400 MeV.

TABLE I—*Principal Data of CERN 600 MeV Synchro-Cyclotron*

Maximum useful radius (n=0·2)	2·27m
Proton energy	600 MeV
Proton velocity	β=0·792
Repetition rate	55 c/s
Initial rate of change of frequency, approximately	−1000 Mc/s
Final rate of change of frequency, approximately	−2000 Mc/s
Acceleration time, approximately	5·5 milliseconds
Average energy gain per revolution	4 keV
Number of revolutions during acceleration	150,000
Initial frequency (theoretical)	28·7 Mc/s
Final frequency (theoretical)	16·6 Mc/s

Our first illustration shows the layout of the building with the accelerator at the centre. The shielding walls are made from heavy barytes concrete (density=3·6) and vary in thickness from 5·1m (east wall) to 5·8m (north wall). The west wall is of ordinary concrete blocks (density=2·4) and is 4m thick. The ceiling is also of ordinary concrete and has a thickness of 1·5m. These walls enclose a hall space measuring 16·25m by 17m by 6·8m high.

There are two long slits in the walls separating the machine from the experimental rooms. These slits may be closed with barytes concrete blocks weighing 2 tons each. A number of such blocks are placed in suitable positions to allow the beams to pass through appropriate channels. For ease of handling, the blocks are stacked on two hydraulic lifting platforms filled with barytes concrete which can be raised to close the lower half of the slits in the shielding walls, the upper half being screened by the blocks.

The larger platform is on the south side (the neutron side) and has a span of 17m, a width of 5·7m, and a vertical stroke of 1·6m. Its lifting capacity is 2000 tonnes. On the north side (the proton side) is the smaller platform, 6·5m span by 5·7m width, with a vertical stroke of 1·1m and a capacity of 400 tonnes.

In order to keep harmful radiations away from the control room, it is connected to the machine building by a corridor 50m long. Around the control room have been built five counting rooms, with facilities for electronic work, with an electronic workshop below them and linked with

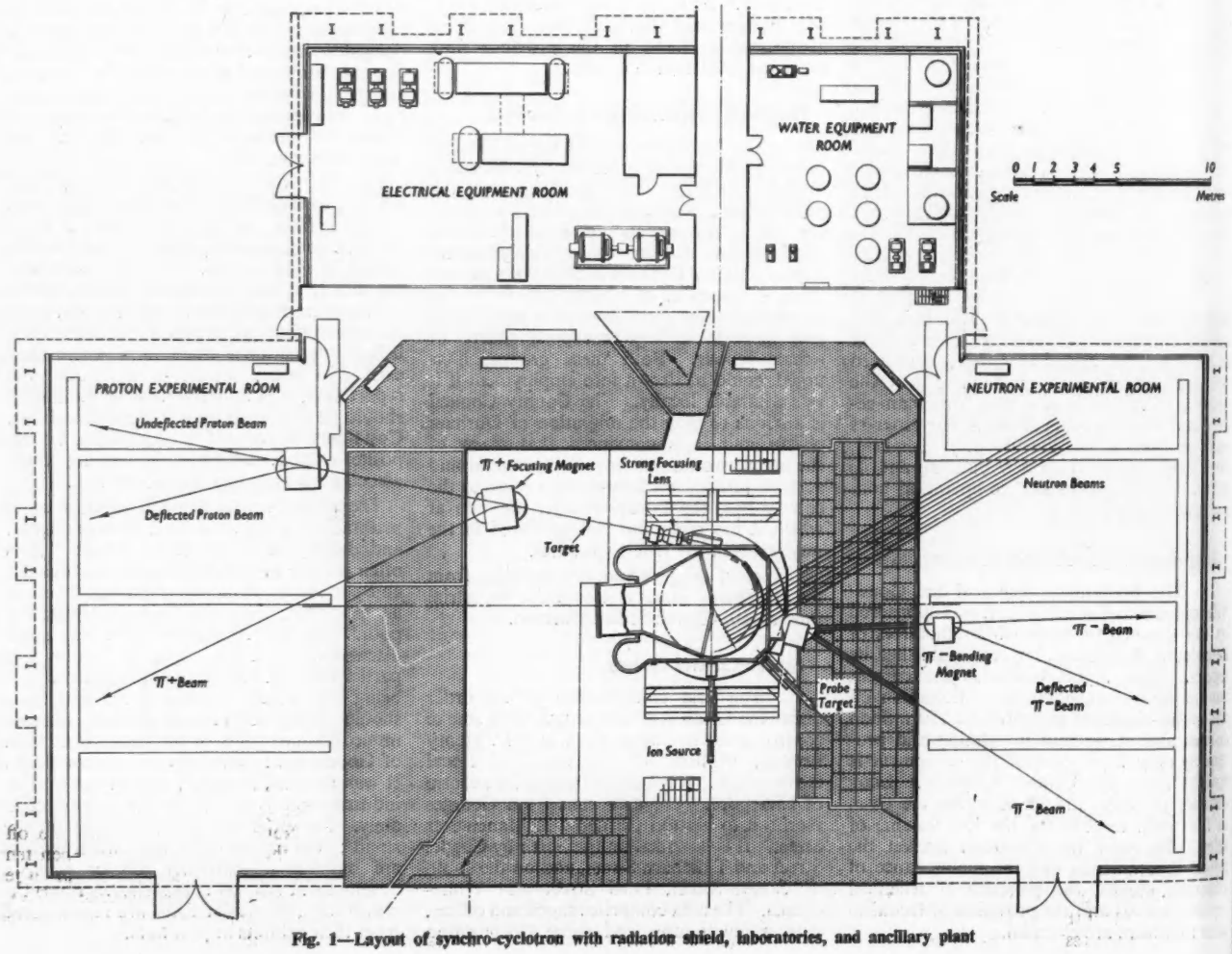


Fig. 1—Layout of synchro-cyclotron with radiation shield, laboratories, and ancillary plant

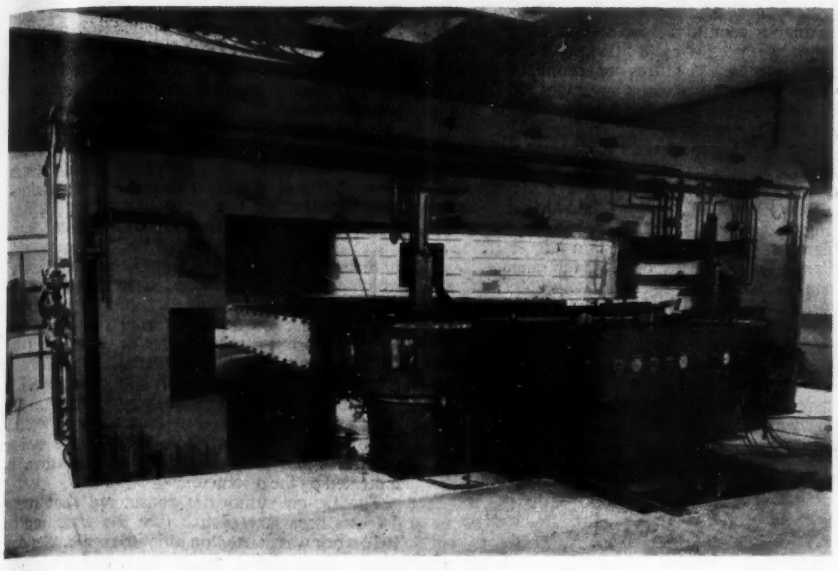


Fig. 2—The 600 MeV synchro-cyclotron

them by a lift. In the control room the operator in charge has control of all the machines used in the operation of the accelerator. He is also in direct contact with the experimental workers in the counting rooms, which are connected by cables with every part of the building.

In the west and east walls of the shield sliding doors have been fitted which are, respectively, 2·8m and 1·5m wide and 4m and 3·2m thick. They weigh 200 and 115 tonnes. The total weight of the shielding is approximately 22,000 tonnes.

Electromagnet.—In Fig. 2 we show the machine with its large electromagnet which contains 2500 tonnes of steel in the form of fifty-four elements, each weighing about 46 tonnes. It is 11m long by 6·5m wide by 6m high, and has a pole diameter of 5·00m, with a pole gap which can be varied between 36cm and 45cm. The useful radius ($n=0·2$) is 2·27m. The coils measure 7·2m in diameter and are 0·9m high. Each weighs 60 tonnes, of which 27 tonnes is accounted for by the aluminium conductors. Their cross section is 1585 square millimetres (38 by 50·2 square millimetres with a 20mm diameter hole for the coolant). The conductors are arranged in the form of double pancakes, nine per coil, each with thirty-seven turns (length 709m), making a total of 333 turns per coil.

At the centre a flux density of 1·88 wb per square metre is produced, while at the radius of 2·27m the flux density is 1·79 wb per square metre. The steel quality on average is 2·08 wb per square metre at 30,000 AT per metre.

Coil resistance at 20 deg. Cent. is 112 Ω, normal coil current (two coils in series) is 1800A. Normal ampere turns total $1·2\times10^6$, maximum ampere turns $1·35\times10^6$. Current is supplied at a tension of 416V, the total energy stored being 27×10^8 joules. The time constant of the magnet is 75 seconds, and the gap ampere turn efficiency at the centre 0·55.

Cooling water flows through each pancake at the rate of 0·5 litres per second, rising in temperature by about 20 deg. Cent. The normal pressure drop is 10 kg per square centimetre.

As soon as the generator had been installed tests based on the Hall effect were carried out in order to obtain an accurate and continuous record of the field strength on both an azimuthal and a radial trajectory. The Hall plates used were of indium phosphite. Irregularities of the field strength are very small and within the limits predicted. It was observed that the presence of the vertical uprights of the magnet frame produced a second harmonic of almost perfect symmetry, the field being greater near the uprights. The stability is greater than 1/10,000 and the temperature coefficient is 7×10^{-4} per deg. Cent.

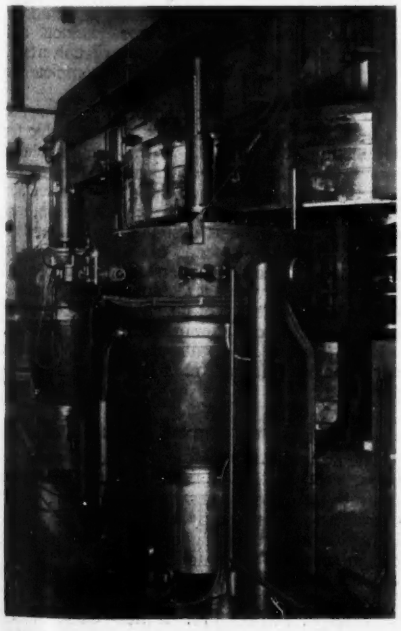


Fig. 3—The synchro-cyclotron showing the vacuum pumps, two sets of coils and the lower yoke members

Vacuum System.—The vacuum system comprises the vacuum chamber, together with two diffusion pumps (Fig. 3) and three rotary pumps. The vacuum tank is of 18/8 stainless steel, 30mm and 60mm thick, and has a volume of 23 cubic metres. Its dimensions are approximately 6·5× 5·5×0·7 cubic metres. The operating pressure is to be 6×10^{-6}mm Hg, but an ultimate pressure of 3×10^{-6}mm can be attained. Pumping time from atmospheric to 10^{-5}mm Hg, with two rotary pumps in operation, is forty minutes.

Each of the rotary pumps has two stages: the low pressure stage has a capacity of 170 cubic metres per hour, and the high pressure stage has a free air capacity of 5 cubic metres per hour. The ultimate pressure attainable by these pumps is 10^{-4}mm Hg. Motor power is 5·5kW per pump, driving the low pressure stage at 335 r.p.m. and the high pressure stage at 400 r.p.m. Each pump has a cooling water flow of 100 litres per hour.

The diffusion pumps each develop pumping speeds of 20,000 litres per second, without baffles, and with baffles 12,000 litres per second.

Warming up of the oil diffusion pumps requires ten to fifteen minutes. Each heater has a power of 12kW and operates on a voltage of 40V; oil capacity is 25 to 50 litres. The amount of cooling water used by each pump equals approximately 1100 litres per hour. At the baffle the temperature ranges from −2 deg. to 0 deg. Cent.

High-Frequency System.—The theoretical frequency range is 28·7 to 16·6 Mc/s. An oscillator input of 50kW is converted into high-frequency output for the dees at 12kV to 4kV. The oscillator tube, a "TBW 12/100," has a maximum plate voltage of 12kV and a plate current of 6A. Six "DCG 12/30" rectifier tubes are employed, giving a maximum rectifier output of 144kW. Rectifier output voltages of 8kV, 10kV and 12kV are available.

The dees have an internal clearance of 12cm and an internal radius of 2·38cm. Their capacitance is 1350pF. The variable condenser had originally been constructed in the form of a 55 c/s tuning fork of aluminium-57S, with a gap range of 26·5mm to 1·5mm and a capacitance range of 280pF to 2200pF. By the end of 1956 this system had not come up to expectations and so it was decided to proceed simultaneously with the construction of a rotating condenser system.

Cooling water flow to the oscillator is 0·8 litre per second, while to the dee, dee liner, stub, &c., the water flow is 1·5 litres per second.

Power Installation.—Three oil-cooled power transformers, totalling 2500kVA, are installed. They are designed for a primary voltage of 18kV, 50 c/s, three phase. There is also the motor-generator transformer, which is rated at 1500kVA, for 18/6/3·3kV, and two low-voltage transformers, each for 500kVA with a transformation ratio of 220V, 18kV/380.

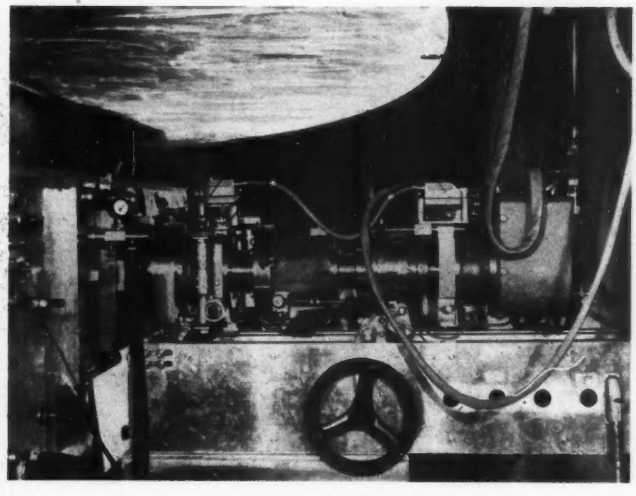


Fig. 4—Ion source of synchro-cyclotron

The motor-generator for the magnet has a rating of 1000kW. The generator maximum current is 2000A, the maximum voltage 500V. The main exciter operates at 440V, 6·8A. The time constant of the main field winding is 0·43 second. The cross-section of the cables to the coils is 4×240 square millimetres. The synchronous motor has a capacity of 1100kW and is wound for 6kV, three phase (starting voltage 3·3kV), and a shaft speed of 1500 r.p.m.

Control System.—The heavy machines of the synchro-cyclotron are started up in the equipment room in order to ascertain that they are functioning properly during the starting period.

They may be stopped either on the spot or by remote control from the control room. All equipment is protected by suitable interlocks against misuse, and faults are notified to the controller by an alarm system. The control system comprises about 200km of conductors, with 800 indicator lights, and 1200 contactors and relays. The maximum control current is 100A at 24V d.c.

Cooling System.—Reference has already been made to the cooling water requirements of some of the principal components of the installation. Two separate cooling systems are used. The magnet system contains some 5 cubic metres of cooling water, which is circulated at the rate of 12 litres per second (primary flow) and 8·8 litres per second (secondary flow), to dissipate a total of 970kW. Three heat exchangers are fitted. The primary water temperature rise is 20 deg. to 40 deg. Cent., the secondary water temperature drop 51·5 deg. to 24 deg. Cent. Primary pressure drop is 0·5kg per square centimetre, secondary pressure drop in the coils is 11kg per square centimetre. The high-frequency auxiliaries require a heat dissipation of 400kW. Primary water flow is 8 litres per second, secondary water flow is 4 litres per second. Secondary water temperature drop averages 50 deg. to 24 deg. Cent. Secondary pressure drop is 4kg per square centimetre.

Two demineralisers and two de-aerators produce purified water of a conductivity of 10^{-6} mho per metre.

Ion Source.—A hot-cathode-arc ion source (Fig. 4) has been installed, which has a tungsten filament 43mm long by 3mm diameter. The filament voltage is about 3V, the current 300A. The arc voltage is approximately 250V, the arc current 2A. The hydrogen flow is 200 cubic centimetres at N.T.P. per hour. At these ratings the internal proton beam is 1μA.

Workshops.—A small mechanical workshop has been set up, mainly for maintenance and minor repairs, with a staff of six men. All heavy mechanical work was done by the C.E.R.N. main workshop.

Dutch Motor Road

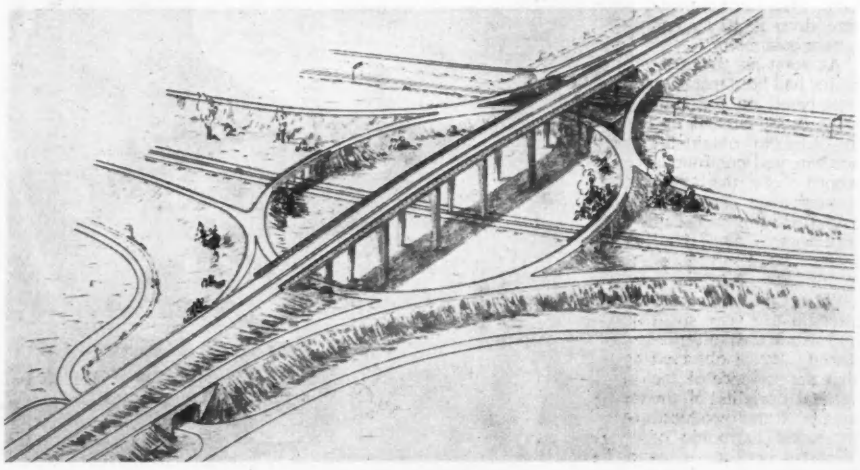
The new motor road described here will complete a high-speed route between Amsterdam and Rotterdam. It will by-pass the Hague, and link the existing motor roads Rotterdam-Hague and Amsterdam-Hague, and also connect with the important motor road passing south-east from the Hague, to Utrecht and towards the German frontier. It is being built on bad ground, at a cost of about £300,000 per mile, and will have a total length of about 30km. The first section is to be opened for traffic soon. The road is known as route 4A.

THE progressive attitude of the Netherlands towards motor road construction, compared with the authorities in this country, is often cited by those who campaign for a reasonably safe and efficient road network. Therefore, recent Dutch activity in the construction of new roads attracts special interest, although, of course, exact comparison between the situation in two countries cannot be drawn. Economic pressure militating against capital expenditure on highways has been somewhat severe in the Netherlands over the past few years. A small national economy has to provide capital for the vast reclamation programmes of the Zuider Zee and Delta projects, and the disaster of the 1953 storm surge with the subsequent hasty programme of sea defence works, put back all these capital programmes, for roads and reclamation alike. Nevertheless, a commendable rate of expenditure on new motor roads has been maintained, and the country is able to feel the benefit of good motor road communications between the principal cities.

The most recent major road to be completed was the Amsterdam-Utrecht motorway, which was opened in 1954. The Velsen tunnel, also a major project, was inaugurated on September 28.* Another large project upon which work is now in progress is the route 4A motor road, which we now describe.

The main road from Amsterdam to the Hague is known as route 4. It is built to motorway standard from the outskirts of Amsterdam as far as Leiden, which it by-passes to the north ; but from this point as far as the Hague, route 4 exists as a general-purpose main road, and passes through a fair length of built-up suburbs at the eastern side of the Hague. The Hague is approached by two motor roads on its southern side, both of which lead into general-purpose roads on the outskirts of the city. Route 13 approaches from Rotterdam, and route 12 from Utrecht.

The aim of the route 4A, which is now under construction, is to link together the existing motor roads, thus providing a motorway route all the way between Amsterdam and the Hague and also allowing the Hague to be by-passed by through traffic on any of these main routes.



Flyover crossing with the new road passing over the Hague-Utrecht motor road and railway. The viaduct will be built when the intensity of traffic on the new road grows sufficiently to overtax the capacity of the roundabout

* Both the Amsterdam-Utrecht motorway and the Velsen tunnel were described in the supplement of Dutch engineering works published in THE ENGINEER of June 11, 1954.

Route 4A starts at Ypenburg, which is roughly 5km from the centre of the Hague in a southerly direction, on route 13 (from Rotterdam). Just a little further north from Ypenburg route 13 enters the crowded Rijswijk suburb, and becomes a general-purpose road. The Ypenburg junction between routes 4A and 13, is built to full motor road standards, which are characteristic of route 4A throughout its length. The new road extends from the eastern side of route 13 in a north-easterly direction (i.e. approximately as a ring road with respect to the Hague) for about 3km, where it crosses route 12, at an " interchange." It then continues in the same general direction, which is straight towards Amsterdam, passing to the south of Leiden, and running into the motorway section of the existing route 4 in the Haarlemmermeer polder, almost 15km east of Leiden. Route 4A will have a total length of about 30km ; that is, it saves about 8km over the existing Rotterdam–Amsterdam route through the Hague and by route 4. But because the congested urban sections of road are by-passed, the saving on the entire route is much greater than is indicated by the distance.

The Dutch authorities considered that route 4A was necessary even before the war, and in 1939 work was started on a limited scale. Serious work was not really undertaken, however, until 1953. The western half of the road, from Ypenburg to just beyond the crossing of the Oude Rijn south of Leiden will be finished and opened to traffic by next spring, except for the small length between routes 12 and 13, which is due to be opened this year. The eastern half continuing from Leiden to the junction with route 4 at Burgerveen is scheduled to be finished by 1960. Between 1958 and 1960, a temporary link using a provincial main road (No. 5) will complete the link to route No. 4.

Intersections and Bridges

When the road is complete there will be eight road junctions along its length of 30km. Of these, we illustrate herewith the junction with route 12 (the Hague–Utrecht), which is one of the busiest Dutch motor roads. Route 12 passes from left to right at the lower level ; behind it, the main railway line is also carried under the new road. It is intended to carry route 4A traffic on the high-level roundabout and the central viaduct shown in the illustration will only be constructed when traffic on the new route has increased sufficiently to justify it.

Other interesting structural works needed along the new route include a bascule bridge over the Oude Rijn (which carries considerable waterborne traffic) and a cutting where the circumferential dyke draining the Haarlemmermeer polder is crossed. The dyke is to be carried over the motor road in a reinforced concrete culvert. Twenty-three viaducts and bridges, and considerable lengths of culverts of various kinds, will be required to complete the scheme.

Approximately 20km of motor road is included in the first stage of this work, which is due for completion next year. This first stage includes four main crossings of other roads, the railway crossings, and the bascule bridge over the Oude Rijn. Seven contractors have been employed on the work, which is designed and supervised by the roads directorate of the Dutch state organisation, the Rijkwaterstaat. The cost of the first stage works is estimated to be about 40,000,000 guilders (i.e. nearly £4,000,000), and of the whole road about 60,000,000 guilders, which is equivalent to about 2,000,000 guilders per kilometre of road, or a little over £300,000 per mile.

Constructional Details

The design of the road calls for dual carriageways, each 7·25m in width, separated by a central reservation generally 4·5m wide ; each carriageway is flanked by a hard shoulder 2·75m in width and a grass verge of 1·75m. The design speed of the road is 80km per hour and the curves are laid out with minimum radii of 10,000m for horizontal curves, and either 10,000m or 20,000m for vertical curves. The only violation of the standards of uninterrupted flow which characterise a motor road is at the Oude Rijn crossing, where the occasional opening

of the bascule bridge will result in interruption to traffic.

From the constructional point of view the road is noteworthy for the extensive soil mechanics investigations which preceded its construction.† The ground over which it passes is almost all very bad, and frequent changes in subsoil conditions and properties were discovered along the route. In general, a solution very typical of Dutch highway construction was adopted, termed "soil improvement" by Dutch engineers. This process consists of excavating the poor-quality soil, generally of a peaty nature but sometimes clayey, over the entire constructional width of the motor road, and replacing it by sand. Since the land is uniformly low-lying, this "soil improvement" is done cheaply by using floating dredgers to dig a canal corresponding to the excavation needed, and then to use hydraulic methods to pump sand into the canal from neighbouring borrow pits. The sand is placed under water and is thus in an optimum state of consolidation. When the canal is filled with sand, carriageway construction proceeds on the improved formation thus provided.

The canal formed by this method of construction was generally about 5m in depth and with a width of 30m or 40m. The depth was calculated from the soil mechanics analyses, on the basis that two-thirds of the settlement to be expected theoretically should occur during the execution of the work. The weak soil was up to 14m in depth, and its complete removal was not feasible economically when such a depth was encountered. The bottom width of the excavation was determined as the intercept at the given depth of lines drawn from the outer edge of the hard shoulders and splaying outward at 30 deg. to the vertical; alternatively, in other parts of the work, 6m clearance was allowed at each side over the intercept of lines drawn at 45 deg. from the outer edges of the carriageways.

When the road is constructed on an embankment—for instance, on the approaches to the Oude Rijn crossing—the filling material was again sand, generally placed hydraulically above the natural ground level. In such situations the natural ground was strengthened by sand piling, penetrating through the top strata of unsatisfactory strength, down to a substratum of sand.

Improvement of the underlying soil by the method just described proved necessary for all but about 2km of the length of route 4A. The total quantity of excavation to be dredged to complete the work is about 4,300,000 cubic metres, and 7,500,000 cubic metres of sand is the total requirement for filling the canal and forming the embankments. Several of the borrow pits also serve as tips for the excavated material.

Concrete and Soil Cement Carriageways

Construction of the carriageways of the new motor road is in reinforced concrete, but soil cement has also been extensively used along more recent lengths of the work, with some saving in cost as a result. On embankments close to structures a surface of concrete or brick setts is used; this again is characteristic of Dutch practice, its purpose being to accommodate settlement. The junction with the structure is made with precast concrete slabs.

Normal concrete construction consists of a thickness of 17cm of concrete with a cement content of 300 kg per cubic metre, topped with a 6cm thickness of richer concrete, with 400 kg of cement per cubic metre. The soil cement carriageway consists of 15cm thickness of soil cement, with 100 kg of cement per cubic metre, topped with a layer of concrete of equal thickness with a cement content of 350 kg per cubic metre. A sand-asphalt joint, nominally 1cm in thickness, separates the two layers; its purpose is to give a level surface for the top layer by taking up the unavoidable irregularities in the soil cement surface.

In constructing the concrete carriageways a strip half the width of the carriageway—3·6m—is concreted; a longitudinal expansion joint separates the two strips in the completed work. The plant used for the work is typical of the large-scale road construction of to-day. Rates of progress of 500m per day have been maintained in concreting these 3·6m strips. Soil stabilisation has been carried out at rates of about 750 square metres daily.

Planning and Economy

The planning of the route and the acquisition of land is of long standing, for constructional work was actually started in 1939. It is interesting to speculate on the choice of route which the Dutch highway engineers would have chosen if the scheme had been started afresh within the last year or two. The route is characteristic of the "outer ring" idea, as it affects the Hague. The tendency to-day is to take the motor road right into the heart of the city, for experience has now shown that outer ring roads do not attract large volumes of traffic in most cases. If route 4A had been taken through the central districts of the Hague, the same "through" route would have been achieved, and if it had been skilfully routed and "fed" by intersections a vast number of the short journeys generated in the city's central area would have been served by it as well. The road would then have been vastly more expensive; but possibly it would have given an even better economic return.

As it is built now, it is considered that if shares had been put on the market to finance it, they would now stand at 200 per cent of their original price. The saving in cost which the road will give at the estimated traffic intensity is computed at 9,000,000 guilders annually. Annual payments of interest, &c., on the cost of the work is put at 3,400,000, giving an annual profit of 5,600,000 guilders equal to a return of 8·7 per cent. An increase of traffic above the estimated figure, which is the common occurrence on new road schemes of this kind, would, of course, give more favourable figures.

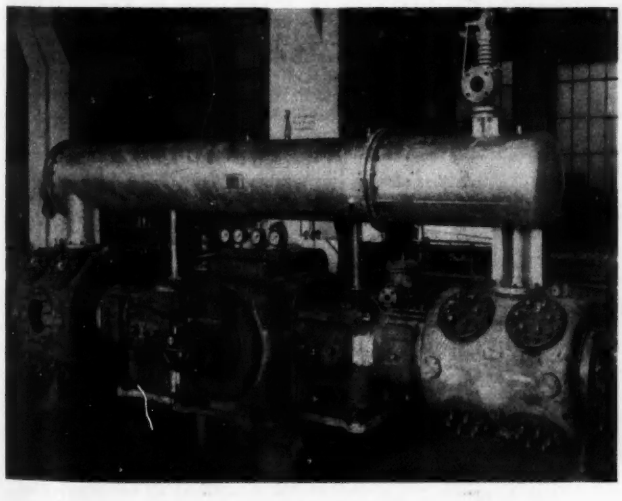
† This soil mechanics work has been described by the Dutch engineer Wever in the journal *Wegen* for March, 1957, as part of an article on route 4A.

Training of Miners and Steel Workers

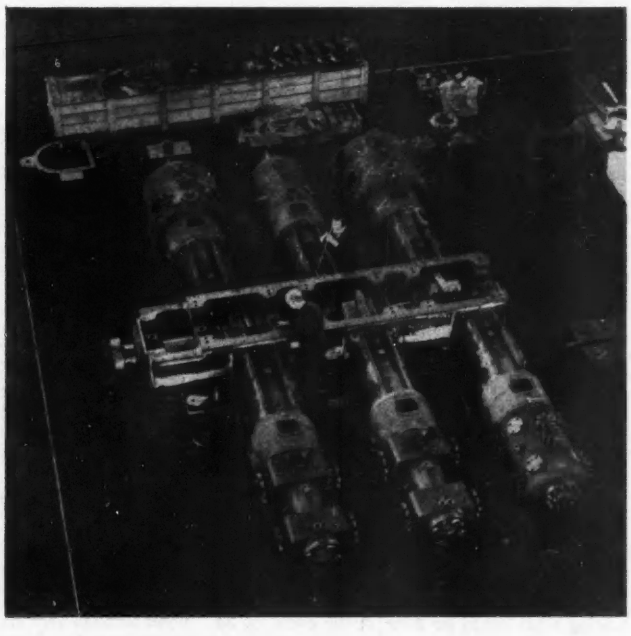
Vocational training experts of the European Coal and Steel Community will visit Britain, from November 25 to December 5, to study on the spot vocational training measures in British coal mines. The experts, whose visit is being organised jointly by the British National Coal Board and the High Authority, are members of the High Authority's special sub-committee on vocational training in the coal industry. At its meeting on September 27, the sub-committee discussed the organisation by the High Authority of a conference in Luxembourg next spring which would bring together delegates from firms and representative organisations to study the experience of the Community and Great Britain in vocational training and the improvement of training methods. The sub-committee also urged the exchange of young apprentices between different countries.

Opposed-Piston Compressors

A compressor design by Demag A.G., Duisburg, uses two, four or six horizontally opposed pistons, which are offset only by the width of the crank. These machines, it is claimed, run very quietly on account of the symmetrical distribution of the inertia forces which exists at all crank angles. Our first illustration shows such a compressor, a two-stage machine surmounted by its intercooler. It absorbs 415 h.p. at 430 r.p.m. and compresses 2910 cubic metres per hour of free ethylene from 2·16 to 22·83 atmospheres. Another design, which has been carried out in several versions, is a four-cylinder, single-stage compressor for compressing 50,000 cubic metres per hour of free coke oven gas from 10 to 21 atmospheres. This requires 2200 h.p., and the machine runs at 375 r.p.m. An interesting example is depicted in our second illustration, which shows a six-cylinder compressor during assembly. The lower row of cylinders compresses 10,000 cubic metres per hour of hydrogen in three stages from 24 to 280 atmospheres, while the upper row compresses 2900 cubic metres per hour of free nitrogen from 1 to 280 atmospheres in five stages. This compressor runs at 296 r.p.m. and consumes 2450 h.p.



Two-stage, opposed-piston compressor for ethylene of 415 h.p.



Compressor handling hydrogen in three stages and nitrogen in five stages

Gas Turbine Ship "John Sergeant"

BY OUR AMERICAN EDITOR

The G.T.S. "John Sergeant" of the U.S. Maritime Administration is believed to be the first ocean-going merchant ship to be powered by a gas turbine only. Her trials, maiden voyage and subsequent operation in the North Atlantic service by the United States Lines have been successful. The gas turbine installed in this former "Liberty" ship is a General Electric 6000 s.h.p. open-cycle, regenerative machine driving a single controllable-pitch propeller supplied by the S. Morgan Smith Company. The vessel attained a speed of 17·5 knots on her maiden voyage and averaged 16·81 knots on her first Atlantic crossing between New York and Southampton.

THE gas turbine ship "John Sergeant," which is illustrated above, is one of the four "Liberty" ships to be converted under the U.S. Maritime Administration's Liberty Ship Conversion and Engine Improvement Programme which was started in August, 1954, when 12,000,000 dollars were appropriated by Congress. Basically, the programme has two major objectives: (1) to evaluate the possibility of increasing the speed of the 1500 "Liberty" ships in the National Reserve Fleet in the event of a national emergency, and (2) to develop and evaluate improved propulsion plants for the new ships of the American merchant navy to be built during the next decade. Two of the conversions were directed toward the first basic objective and two towards the second. The G.T.S. "John Sergeant" fulfils the second objective because its open-cycle gas turbine represents an entirely new marine prime mover.

It is of interest to note that the first ship in the programme, the s.s. "Benjamin Chew," was converted to conventional steam turbine drive using existing or modified "Victory" ship equipment. Enlarged superheaters were installed in the original "Liberty" ship boilers, and "Victory" ship turbine and gears taken from the warehouse were modified and installed. The steam temperature was increased to 750 deg. Fah. In other respects the main propulsion plant was upgraded to the maximum extent. The ship completed her sea trials in July, 1956, when she developed 5975 s.h.p. at 100·4 r.p.m. and attained a trial speed of 15·06 knots. She is now under charter to the United States Lines Company for its South Atlantic - Northern European berth service. This conversion is, from an engineering point of view, the most marginal of the four ships because the equipment is modified and upgraded to the maximum extent. This is in accordance with the concept of ascertaining what could be done in the event of an emergency.

The second ship, the M.V. "Thomas Nelson," was converted to geared diesel drive using two 3125 b.h.p. Baldwin-Lima-Hamilton vertical in-line seven-cylinder, two-cycle, single-acting engines. The "Thomas Nelson" successfully passed her sea trials in August, 1956, developing a total of 5625 s.h.p. and attaining a speed of 17·3 knots, burning heavy fuel. In addition to the engine change a new bow was added, giving the ship finer lines forward and an overall length increase of 25ft. This same bow change was made on the second, third and fourth conversions. Only the s.s. "Benjamin Chew" has the original "Liberty" ship hull form.

The third and fourth conversions are directed primarily at the second basic objective: the development and evaluation of new power plants. Since the G.T.S. "John Sergeant" is the subject of this article, her power plant will be described later. The fourth conversion, the G.T.S. "William Patterson" is equipped with a free-piston gas-generator-turbine propulsion plant. This power plant produces hot gas in six self-sustaining gas generators having two opposed pistons, which are not mechanically connected, using a two-stroke diesel cycle. The hot gases are discharged through two simple turbines driving the propeller through a common reduction gear. The six gas generators are of the basic "Sigma GS-34" design and construction and have been built by General Motors under licence from the French firm Société d'Etudes Mecaniques et Energetiques. Each gas generator is rated at 1325 gas horsepower with an 825 deg. Fah. temperature and 45 lb per square inch gauge discharge pressure to the turbines. There are two 3000 s.h.p. turbines built by Alsthom in Belfort, France, and each is equipped with astern stages. The test stand trials were conducted by the Cleveland Diesel Engine Division of General Motors. The results of these tests have been encouraging and show that the plant will produce 6000 s.h.p. with a specific fuel consumption of 0·43 lb per s.h.p.-hr for the main unit only. The units were installed in the ship by the Bethlehem Steel Company, Shipbuilding Division, at Baltimore, Maryland, and sea trials are scheduled for this autumn. As a result of the test stand trials it is reasonable to predict that the ship should perform well and the ship specific fuel rate should be about 0·48 lb per s.h.p.-hr. overall. Although the noise level will probably be higher than in a motor vessel, there will be far less vibration and no torsional vibration problem. The backing qualities will be good, since complete reversal of the shaft can be obtained in about thirty seconds or less and a total of 2100 s.h.p. astern is estimated.

After the "William Patterson" will have been in service for approximately a year and a half, the Maritime Administration may advance the development of free-piston plants further by installing after-burning to increase the power output, an effect which is possible because the gas discharge from the gas generators contains about 75 per cent of the original oxygen. The installation will necessitate, in addition to the afterburner, a new 8000 s.h.p. turbine and a controllable-pitch propeller. In addition, a hardened and ground reduction gear will be used to develop further this kind of gear for merchant ship use. When installed, the ship with afterburning is expected to have a fuel consumption of about 0·44 lb per s.h.p.-hr at 5000 s.h.p., corresponding to 16·2 knots, and a full-power rating of about 7700 s.h.p., corresponding to about 17·8 knots with a specific fuel consumption of about 0·49–0·50 lb per s.h.p.-hr. Both of these fuel consumptions are for the main unit only. This development will provide a basis for a useful evaluation of two basic free-piston power plants, one with and one without afterburning. As a result of the development and experience to date, it is felt that the free-piston plant will be most competitive in the horsepower range below 7000 or 8000 s.h.p.

Gas Turbine Power Plant

The G.T.S. "John Sergeant" is equipped with an open-cycle regenerative gas turbine of the two-shaft design. The main emphasis of the conversion was directed towards the gas turbine, the

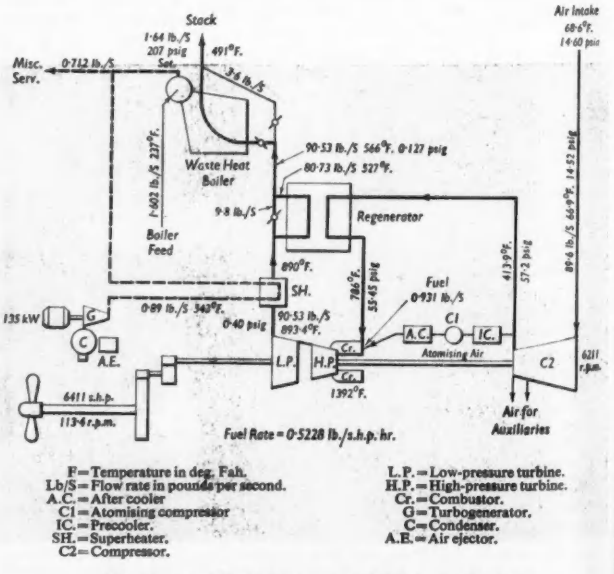


Fig. 1—Gas flow diagram and trial heat balance

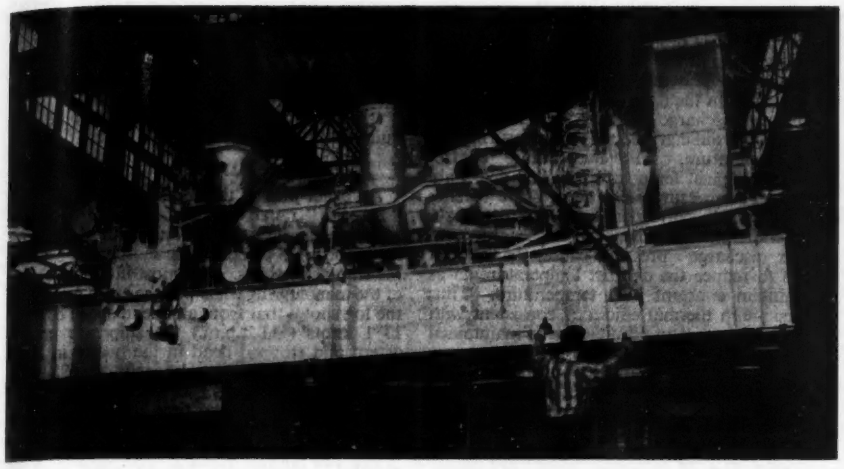


Fig. 2—General Electric open-cycle, regenerative gas turbine prior to installation in the "John Sergeant"

regenerator, the controllable-pitch propeller and the controls. Otherwise, every effort to use either existing equipment or warehouse equipment was made in the interest of economy. Fig. 1 is the trial heat balance diagram and shows the gas flow of the plant. A view of the completed propulsion unit leaving the makers' works is shown in Fig. 2.

The gas turbine is an open-cycle regenerative two-shaft machine consisting of an axial-flow fourteen-stage compressor driven by a high-pressure gas turbine and has a separate low-pressure load turbine in the same casing. The high-pressure turbine is designed for an operating inlet gas temperature of 1450 deg. Fah. and a rated full-load speed of 6900 r.p.m. The low-pressure turbine is designed for an operating exhaust temperature of 950 deg. Fah. and a full-load speed of 5517 r.p.m. at 110 propeller r.p.m. The low-pressure turbine is equipped with variable-area nozzles to facilitate control and to improve part-load efficiency. The gas turbine unit was designed for a normal power rating of 6000 s.h.p. with a maximum rating of 6600 s.h.p. at an 80 deg. Fah. ambient temperature. However, one of the principal advantages borne out by the sea trials and the maiden voyage is the overload capacity of the unit. As is noted later, it easily developed 7500 s.h.p. without ever reaching the full compressor speed of 6900 r.p.m. The gas turbine and controls were supplied by the General Electric Company, of Schenectady, New York.

The performance of the controllable pitch propeller also has proved to be very good. It was supplied by the S. Morgan Smith Company, of York, Pennsylvania, and is a four-bladed, 17ft 6in diameter, hydraulically-operated unit with the servomotor and oil transfer unit assembly situated in the shaft alley. A guided spider controls the blades through a pitch range of 20·2ft ahead to 15·8ft astern. The maximum stroke of the piston is 11¾in. The propulsive coefficient of the propeller at the designed ahead pitch setting of 17·5ft and 6000 s.h.p. is 0·758. At 3000 s.h.p. and 7500 s.h.p., the propulsive coefficient is 0·800 and 0·747 respectively. For comparison purposes, a similar fixed propeller would have a propulsive coefficient of 0·775 at 6000 s.h.p. ; a propulsive coefficient of 0·783 at 3000 s.h.p. and a propulsive coefficient of 0·760 at 7500 s.h.p.

The propeller assembly and hydraulic power unit are shown during test at the maker's works in Fig. 3. The propeller was designed to absorb 6000 s.h.p. when rotating at 110 r.p.m. The blades are actuated by means of a connecting rod attached to a servomotor situated inboard within a section of shafting. The servomotor piston is positioned by introducing oil through a stationary around-the-shaft oil transfer unit equipped with lapped metal-to-metal oil seals between this unit and the rotating shaft. The connecting rod from the servomotor is attached to a spider which, through a system of links and levers, operates the blades. As the oil is admitted to either side of the servomotor piston, causing linear movement of the connecting rod and piston, the blades are rotated to any desired position. The blades are designed to be the weakest element of the propeller in order to prevent damage to the hub mechanism when striking underwater objects.

The nickel-aluminium bronze blades are held in their sockets by means of a patented bayonet blade retention device and tightened by a wedge assembly. During shop assembly, one blade was removed and replaced in less than thirty minutes without disturbing the operating mechanism. Each of the four blades was carefully hand finished to exact contours and thicknesses, so that the final blade weights varied less than 0·4 per cent. Pressurised oil for moving the blade servomotor is provided by two motor-driven oil pumps. An accumulator is provided with pressure switches, to maintain a constant pressure together with a reserve in the event of power failure. The tank has sufficient oil for two and a half cycles at full power. The hydraulic system is designed to move the blades through one complete cycle in eight seconds.

The gas turbine and propeller controls are integrated so that the engine can be controlled by a single lever from either the bridge or the engine-room. In addition, a separate lever with a selsyn generator is provided on the engine-room console for independent control of propeller pitch.

Description of Vessel

The "John Sergeant," after her original delivery by the Bethlehem Fairfield Shipyard, of Baltimore, in 1942, was operated under a General Agency Agreement by the Marine Transport Lines until July, 1947. For part of the time she was engaged in carrying prisoners of war from North Africa to the United States. She was placed under bareboat charter by the Marine Operating Company and later by the States Marine Corporation, of Delaware, until she entered the U.S. Reserve Fleet at Mobile, Alabama, in July, 1948. She was chartered by the Marine Navigation Company from August, 1948, to October, 1949, placed in reserve at Beaumont, Texas, then operated under general agency by the Luckenbach Steamship Company during the emergency following the outbreak of war in Korea, from June, 1951, to July, 1952. She was then placed in reserve at Wilmington, North Carolina, until September, 1955, when she was withdrawn to become an experimental ship.

The major change to the basic "Liberty" ship during the conversion was the new bow. As mentioned previously, this was done primarily to improve the sea-keeping qualities at the increased speeds. After considering the various possibilities, it was decided to cut off the old bow between Frames 38 and 39, 110ft aft of the perpendicular, and add an additional 25ft to the length between perpendiculars.

The rudder was notched to allow for the somewhat larger propeller hub and a new contra-rudder was installed. Because of the added speed, it was necessary to change the steering engine and a spare "Victory" ship unit taken from the Maritime warehouse was modified and installed. Model basin tests were run on the new lines and the trial results, which will be given later, check closely with the model basin results. A deep tank was installed in No. 3 hold for the purpose of assisting the trim and draught in light condition. No. 2 hold was double-ganged and although two steam winches were used, it is planned that they will be replaced at a later date with new hydraulic winches. This will permit an evaluation at the No. 2 hold of the new winch. The general characteristics of the ship, as modified, are as follows :

Length overall	467ft 2½in
Length between perpendiculars	441ft
Beam, moulded	56ft 10½in
Draught, full load	26ft 7in
Depth, moulded	37ft 4in
Displacement, full load, tons	13,825
Lightship weight, tons	4956
Deadweight, tons	8869
Fuel oil, tons	1000
Diesel oil, tons	102
Fresh water, tons	410
Register gross tonnage	7280·23
Register net tonnage	4481
Crew	37

Sea Trials

The official sea trials were run by the Newport News Shipbuilding and Dry Dock Company, who had undertaken the conversion of the vessel at their Newport News yard in Virginia. During the trials the shipyard was left on four successive days from September 11 to September 14, 1956. The weather was excellent with smooth seas and ambient temperatures varying from 65 deg. to 80 deg. Fah. The trials were very successful and the gas turbine, its auxiliaries, the controllable-pitch propeller, the main controls and the ship in general performed according to the highest expectations. The trials attracted wide attention and, in addition to about 600 guests from the United States, there were many visitors from abroad. Those attending were agreeably surprised at the complete lack of vibration, the low noise level of the gas turbine, the outstanding manœuvrability of the ship, the absence of soot due to complete combustion, the ease with which the gas turbine unit could be operated, the excellent specific fuel rate, and the overload capacity of the turbine.

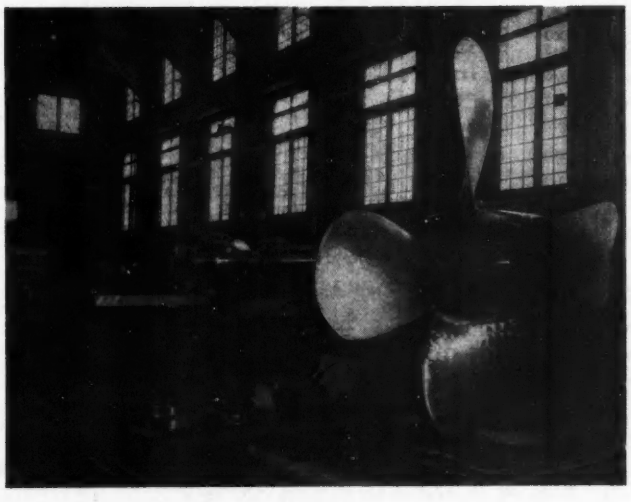


Fig. 3—Controllable-pitch propeller assembly with hydraulic power unit at maker's works

Basically, the sea trials included the following, which were run with a

displacement of about 8035 tons and a draught of about 11ft 1in forward and 21ft 6in aft :—

Reduced power economy runs.

Normal full power and economy runs.

Maximum continuous power endurance and economy runs.

Reduced power trials at reduced pitch.

Reduced temperature run to test simulating burning of unwashed oil.

Ahead steering tests.

Crash astern and crash ahead tests and astern endurance runs, including astern steering.

Z-manœuvres and circle tests.

Special manœuvring runs using two-lever control.

Propeller standardisation.

Trial Results

A summary of the power and economy runs is given in Table I and the trial heat balance at normal power is shown in Fig. 1. The fuel economy at normal power, as shown in Table I, was 0·5228 lb per s.h.p.-hr. This is better than the calculated rate of 0·546 lb per s.h.p.-hr and is considered excellent for a power plant in this horsepower range. The improvement in fuel rate can be accounted for partially by the slightly lower ambient and the higher power rating. However, there is no doubt that the plant met the guaranteed fuel rate. It is obvious that an even better fuel economy could be attained in a completely new ship without the old steam auxiliaries and modified boiler.

It is interesting to note that even during the 7500 s.h.p. run shown in column 5 of Table I the compressor set never attained its full speed of 6900 r.p.m., indicating that the unit was not operating at maximum capacity. Therefore, although the ambient temperature of 69·9 deg. Fah. did account for approximately 404 additional horsepower, the unit has a capacity greatly in excess of 7500 s.h.p. at the designed inlet temperature of 80 deg. Fah. As noted, the overall fuel rate for the ship at 7514 s.h.p. was 0·5144 lb per s.h.p.-hr., which is significantly better than a comparable steam turbine installation. The maximum power obtained was 7871 s.h.p. for a half-hour period on September 11. The maximum speed during this period was 18·05 knots.

The turbine is designed for the maximum of 1450 deg. Fah. at the inlet and 950 deg. Fah. at the exhaust. The turbine inlet temperature is calculated from the exhaust temperature and the compressor discharge pressure. This is necessary owing to the difficulty of reliably measuring the inlet temperature. The temperature control limits the exhaust temperature to 950 deg. Fah. until the compressor discharge pressure reaches the value which corresponds to 1450 deg. Fah. inlet temperature. Further increases in compressor discharge pressure cause the control system to reduce the exhaust temperature so as to maintain constant inlet temperature. Thus the maximum thermal efficiency consistent with the design temperature limitations is maintained over the normal operating range.

The last column of Table I gives the results of the simulated unwashed fuel run and shows that even with untreated fuel oil the unit can develop 4322 s.h.p. at 1200 deg. Fah., a temperature level below which untreated fuel oil can be burned without danger of corrosion and/or depositing. The plant was operated with one burner disconnected to simulate conditions when changing burners under way. Single-lever control was used, but the lever was not in its most advanced position. Under these conditions the unit developed 3173 s.h.p. at 65 r.p.m. with a pitch of 17·9ft. resulting in a speed of 14·5 knots. On the astern endurance run (column 9), Table I, 4187 s.h.p. was developed. Actually, the full 6000 s.h.p. could have been developed, but because of the steering gear equipment used in the conversion, the astern power was intentionally limited. This is another of the many advantages which can be attained in a new ship, designed especially for such an installation.

Table II—*Engine Room Noise Levels.*

	Decibels
Gas turbine unit	96–98
Main reduction gear :	
After end	102
Forward end	105–107
Air intake above bridge deck	102
Steam turbo-generator set	98
Motor-driven air compressor :	
Off	101
On	106
Diesel-generator set	116

During the maximum power run noise level readings were taken with a conventional wide-band overall level noise meter without filters. The readings on the principal components are given in Table II.

It should be noted that the gas turbine is the quietest equipment in the engine-room.

Manœuvring

An exact plot of the trials was maintained by "Raydist" radar equipment. Since the equipment is accurate to within one-tenth of 1 per cent it was possible to determine closely the speed of the ship at all times. The most interesting phase of the manœuvring trials was the crash astern, and the log shows that from an ahead speed of about 17·1 knots (111 r.p.m.) the ship was crashed astern and stopped dead in the water in 2 min and 52 sec with a head reach of 698 yards measured with a Dutch log. The controls were on single lever and the time for complete propeller pitch reversal was 18 sec. As the propeller went through zero pitch the speed increased to about 122 r.p.m. and then decreased until the arbitrarily limited astern power (3600 s.h.p. at 85 r.p.m.) was obtained. One of the interesting aspects of the pneumatic control system is the possibility of quick reversal. If the single control lever is brought back slowly to the natural position a controlled orifice regulates the unloading of the turbine in about 26 sec, the pitch reversal in about 8 sec and 26 additional seconds to bring the turbine back to normal power. However, a rapid movement of the control lever has the basic effect of virtually by-passing the orifice and astern power is obtained in 18 sec or less. On one of the crash asterns from 6500 s.h.p. complete reversal was obtained in 15 sec. The only restriction is when the unit is operating above 7000 s.h.p., where there is a danger of the revolutions increasing above 133 r.p.m. as the propeller moves through zero pitch, and actuating the low-pressure turbine overspeed trip which would cause a shutdown. Actually, this occurred at one time during the trials when a crash astern was made from about 7500 s.h.p. It was interesting to note the considerable braking action of the propeller blades in the zero pitch position after

Table I—*Power and Economy Sea-Trial Summary*

Trial	3000 s.h.p. economy run on Bunker C	4500 s.h.p. economy run on Bunker C	6000 s.h.p. economy run on Diesel	6000 s.h.p. economy run on Bunker C	7500 s.h.p. economy run on Bunker C	3000 s.h.p. reduced pitch on Bunker C	4500 s.h.p. reduced pitch on Bunker C	4500 s.h.p. reduced pitch on Bunker C	Astern endurance run	Simulated unwashed fuel oil
Date	Sept. 11, 1956	Sept. 11, 1956	Sept. 12, 1956	Sept. 11, 1956	Sept. 11, 1956	Sept. 14, 1956	Sept. 12, 1956	Sept. 14, 1956	Sept. 12, 1956	Sept. 13, 1956
Time for summary	8.30–9.30 a.m.	9.45–10.45 a.m.	11.45–12.45 a.m.	12.30–4.30 p.m.	4.45–6.45 p.m.	8.30–9.30 a.m.	9.15–10.15 a.m.	9.45–10.45 a.m.	2.30–3.0 p.m.	3.30–4.30 p.m.
Displacement, tons	8047	8047	8028	8047	8047	7853	8028	7853	8028	8024
Draught :										
Forward	11ft 2in	11ft 2in	11ft 2in	11ft 2in	11ft 2in	10ft 8in	11ft 2in	10ft 8in	11ft 2in	11ft 1in
Aft	21ft 5in	21ft 5in	21ft 5in]	21ft 5in	21ft 5in	21ft 4in	21ft 5in	21ft 4in	21ft 5in	21ft 5in
Speed, knots	14·9	16·3	17·2	17·31	17·9	15·9	17·0	16·4	—	—
Propeller r.p.m.	89·6	106·7	111·2	113·4	112·7	116·1	114·6	116·1	81·9	101·2
Propeller pitch, ft	17·6	17·2	17·6	17·4	18·3	12·3	14·8	14·8	—	—
Shaft horsepower	3164	5238	6028	6411	7514	3207	4764	4780	4187	4322
Per cent regenerator by-pass, damper open	0	100	0	41	0	0	100	0	—	0
Per cent regenerator, damper closed	83	0	0	0	0	0	0	0	—	0
Ambient temperature, deg. Fah.	65	68·5	72·0	68·6	69·9	74·8	71·6	74·8	72·0	79·3
Barometric pressure, inches Hg	29·78	29·76	29·70	29·72	29·69	29·58	29·70	29·56	29·70	29·59
Compressor inlet temperature, deg. Fah.	65·0	66·7	71·2	66·9	69·0	75·6	70·0	77·3	71·7	79·7
Compressor inlet pressure, in H_2O	1·5	1·7	2·1	2·3	2·8	1·4	1·7	1·9	1·8	3·0
Compressor r.p.m.	5360	5680	6075	6211	6611	5515	5765	5715	5750	6875
Compressor discharge temperature, deg. Fah.	334·5	372·4	410	413·9	447	352·7	377	381·7	379	463·2
Compressor discharge pressure, pounds per square inch	37·6	47·7	53·9	57·2	65·7	38·3	47·3	46·3	58·0	62·1
Pressure drop, compressor discharge to combustor inlet, in Hg	2·75	3·15	3·45	3·57	4·03	2·8	3·18	3·2	3·29	4·1
Combustor air inlet temperature, deg. Fah.	698·8	740·1	795·1	786·0	798·1	751·3	775·1	792·8	776·9	664·4
Turbine inlet temperature (estimated) deg. Fah.	1280	1390	1400	1392	1420	1258	1333	1354	1385	1200
Turbine inlet exhaust temperature, deg. Fah.	839·9	926·6	907·0	893·4	885·5	868·6	889·3	906·6	886·6	736·2
Turbine inlet exhaust pressure, in H_2O	5·92	7·77	8·65	11·06	13·49	4·53	5·67	5·37	5·69	8·86
Regenerator gas outlet temperature, deg. Fah.	417	450	533·7	527	568	474	500	511	509·2	522
Regenerator gas outlet pressure, in H_2O	1·75	2·70	3·02	3·51	5·28	0·10	0·28	0·0	0·40	0·65
Waste heat boiler gas inlet temperature, deg. Fah.	—	572	531·8	566	580	—	—	—	—	—
Stack temperature, deg. Fah.	—	479	481	491	531	—	—	—	—	—
Waste heat boiler feedwater temperature, deg. Fah.	—	238	235	237	237	—	—	—	—	—
Waste heat boiler pressure, pounds per square inch gauge	—	199	203	207	209	—	—	—	—	—
Superheater outlet temperature, deg. Fah.	—	541	554	543	541	—	—	—	—	—
Generator load, kW	120	115	118	135	133	126	120	159	144	143
Type fuel	Bunker C	Bunker C	Diesel	Bunker C	Bunker C	Bunker C	Bunker C	Bunker C	Diesel	Diesel
Fuel temperature, deg. Fah.	213	221	80	217	216	225	219	233	80	80
Fuel consumption, turbine, as burned pound per hour	2208·2	3161·7	3112·1	3363·6	3878·5	2008·1	2613·6	2515·8	2453·0	3113·5
Fuel rate, pounds per s.h.p. hour*	0·6959	0·6015	0·5463	0·5228	0·5144	0·6240	0·5467	0·5254	0·6199	0·7622
Fuel consumption, oil-fired boiler, as burned, pounds per hour	417·8	0	0	0	0	571·0	432·9	603·7	0	504·7
Plant fuel rate, pounds per s.h.p. hour*	0·8275	0·6015	0·5463	0·5228	0·5144	0·8042	0·6375	0·6508	0·6198	0·8790

* These rates are based on a higher calorific value of the fuel of 18,500 B.Th.U. per pound.

the turbine tripped out. The plant was back on the line within three minutes after the trip-out.

During manœuvring and at powers below 4500 s.h.p. it was necessary to fire one of the boilers to produce the necessary auxiliary steam. This would not be needed in a completely new design because the main auxiliaries would not be as dependent on the boiler. It should be remembered that the port steam load of the "John Sergeant" is higher than her underway load, because the old steam winches were left on board. The ship was crashed ahead from 85 r.p.m. astern to dead in the water in 1 min and 19 sec with an astern reach of 200 yards as measured by a Dutch log.

Propeller Performance

The combination of the controllable-pitch propeller with the gas turbine is an ideal one. Each complements the other and it was often difficult to decide if the credit for the excellent performance belonged to the turbine or the propeller. As mentioned in the foregoing, the propeller controls were most effective. Tests were run at various pitch settings and varying revolutions to obtain the performance curves shown in Fig. 4.

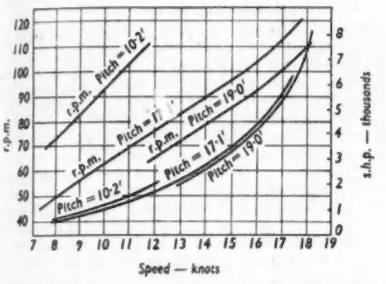


Fig. 4—Performance curves of controllable-pitch propeller

One of the difficulties encountered with the propeller was a slight variation of about 0·4ft pitch from the set position, and it was necessary to average the observed pitch settings during the various runs. It is believed that this condition was brought about by the entrapment of air and will be eliminated by adjustments to the pump and minor modifications to the piping system. It also was found to be desirable to install a pump of 3 gallons per minute capacity which operates continuously to make up leakage in the oil distributor. By this slight modification, the larger manœuvring pumps will not be in use underway.

Propeller residual power tests also were run to determine the maximum number of reversals possible with both hydraulic oil pumps secured. At the start of the test, revolutions per minute were 95 and the pitch was 17·2ft ahead; five and a half pitch reversals were obtained using the propeller pitch control lever at the engine-room console before the hydraulic tank pressure had dropped to the point where it was no longer possible to move the blades. This demonstrates the protection available for pitch reversal in the event of a complete electrical failure. In addition, it is always possible to move the blades by use of the manually operated pump situated in the shaft alley.

During the trials the propeller was run at reduced pitch at approximately half power and normal revolutions per minute to determine the effect on specific fuel consumption. Comparing columns 1 and 6 in Table I it shows that the improvement in fuel rate was about 3 per cent. Hence, the controllable-pitch propeller obtains better fuel economy at low loads by permitting the turbine to operate at normal revolutions per minute.

The Maiden Voyage

The maiden voyage of the G.T.S. "John Sergeant" began officially on Saturday, October 6, 1956, when she departed from Ambrose Lightship bound for Southampton and Bremerhaven with cargo. The ship was operated under General Agency by the United States Lines Company for the U.S. Military Sea Transportation Service, an agreement which the Maritime Administration had been able to arrange because of the keen interest and sincere desire of the M.S.T.S. to co-operate in the development of gas turbines for merchant ships.

The cargo was of a general type and was mostly cubic, having a total of 5106 measurement tons and 2250 net tonnage. The displacement of the ship was 10,071 tons, resulting in a draught of 17ft 10in forward and 22ft aft. It is unfortunate that more deadweight was not available because the propeller was continuously breaking the surface during the rough weather on the outbound leg of the maiden voyage.

Diesel fuel was used on the maiden voyage. Actually, there was no necessity to do so, but it was decided to give the ship and engine department a chance to get settled down before introducing the one additional step of fuel oil washing and treating. Also, it seemed logical first to establish the reliability of the gas turbine by running the unit at full capacity during the maiden voyage. Bunker C fuel oil will be used on all subsequent voyages and from the experience gained during the trials, no handling difficulties are anticipated.

Since diesel oil was used during the maiden voyage, the gas turbine unit was not subjected to any cleaning during the voyage. It was recognised that there might be some sodium deposits in the compressor, but since the overall efficiency of the unit remained more or less constant, it was decided to wait until the ship arrived in Bremerhaven so that a visual inspection of the blading could be made prior to any washing. This was done and while the compressor had a very slight sodium deposit, the turbine wheel was in perfect condiiton. Based on this observation it was decided that in the future the unit would be washed with both water and compound after each eight days of operation.

There are two methods of cleaning the gas turbine unit. For water washing, water is injected into the low-pressure end of the compressor in quantities of about 10 gallons per washing. The water can be either carried or made aboard ship, but it is considered that the latter is preferable since better control can be exercised. The second method is the use of a solid cleaning compound injected into the low-pressure end of the compressor. This compound is an equilibrium regenerated precipitator in which aluminium oxide is used as a catalyst.

As was to be expected on the North Atlantic, the ship encountered rough weather for the first three days *en route* to Southampton. Starting in the afternoon of the second day, rough seas and winds up to force 10 continued until the afternoon of the third day. On the fourth and fifth days, the seas were moderate and although mostly overcast and hazy, the winds were light. On the afternoon of the sixth day, heavy swells and easterly head winds were encountered. The ship performed excellently in the heavy weather, and the captain was pleased with her behaviour.

Outward bound, the "John Sergeant" sailed the 2950 miles between Ambrose Lightship and Bishop's Rock in 7 days 7 h and 27 min, at an average speed of 16·81 knots.

Gas Turbine Performance

The gas turbine lived up to its trial performance and operated smoothly and quietly throughout the voyage. In order to establish definitely its ruggedness and continuous overload capacity, it was decided to operate in excess of 7000 s.h.p. on the outward voyage. The propeller and shafting have a sufficient factor of safety to allow such operation. It was recognised that, while the specific fuel rate would be excellent, the total barrels per day would be high because the converted "Liberty" is not the ideal hull form for a sustained sea speed of 17 knots or more. Homeward bound and on subsequent voyages the unit was operated at about 6000 s.h.p. and the total fuel consumption at normal rating has been good. It now appears that the annual cost of fuel for the "John Sergeant" will be about 12 per cent less based on specific fuel rates. In addition, since the average ambient temperature on the Atlantic will be considerably less than the designed 80 deg. Fah., there will be a further reduction in fuel costs because the unit will have a consumption based on a lower output, while maintaining the normal rating of 6000 s.h.p. at all times. Thus, if the yearly average ambient temperature is, say, 50 deg. Fah., the total fuel cost of the "John Sergeant" will be another 10 per cent lower, or a total of 22 per cent less than that of a "C-2" "Liberty" vessel.

For the first two days outbound the compressor speed was maintained at 6700 r.p.m. and the propeller pitch was set at about 19ft, maintaining the shaft revolutions per minute just below the point where the low-pressure turbine speed bias would reduce the turbine inlet temperatures. After the second day, the compressor speed was increased to its full rating of 6900 r.p.m., and the unit temperature control was kept on the compressor discharge bias, maintaining designed turbine inlet temperature for the remainder of the voyage. Propeller pitch was varied between 17·5ft and 19·5ft with the latter setting being maintained most of the time. Ambient temperatures varied between 60 deg. and 78 deg. Fah.

The trials and maiden voyage showed that the gas turbine control system makes the unit automatic. Even during the roughest weather the compressor speed remained absolutely steady and the only variation in power turbine speed was due to the propeller breaking the surface as the ship pitched. This pitching action is another essential reason for a separate power turbine because the regulation of a single shaft unit in a heavy sea would be almost impossible. The control system of the "John Sergeant" works perfectly and there is no hunting or oscillating of any description.

The temperature control system consists of two temperature detectors, a relay control assembly and a temperature governor. The two temperature detectors are situated in the exhaust duct and generate an air pressure signal universally proportional to temperature. The relay control assembly consists of one averaging relay, one primary relay, one compressor discharge pressure bias relay, one load turbine speed bias relay, one pressure selector relay, one pressure-reducing valve and one air filter. The averaging relay receives the two signals from the two temperature detectors and transmits the averaged signal to the primary relay. The pressure selector relay selects the higher signal from either the compressor discharge pressure bias relay or the load turbine speed bias relay and transmits this pressure to the primary relay. The net output signal pressure of the primary relay is fed to the temperature governor, which controls fuel. The unit may be kept off the low-pressure turbine speed bias by keeping the low-pressure turbine speed below the bias point by an increase of propeller pitch. This feature is especially useful in rough weather when the surges of revolutions per minute due to propeller breaking the surface ordinarily would cause a reduction in power.

The engineer's log abstract shows that the average shaft horsepower rating on the voyage from New York to Southampton was 7263 s.h.p. with a specific fuel rate of 0·516 lb per s.h.p.-hr and an average consumption of 295 barrels per day.

From the standpoint of economics, the conversion of the "John Sergeant" to gas turbine propulsion and controllable-pitch propeller constitutes an excellent return from a research and development project. The total cost breakdown is as follows:—

Plans and specifications	81,000 dollars
Gas turbine and controls	635,000 dollars
Main reduction gear	213,000 dollars
Controllable-pitch propeller	119,000 dollars
Conversion and installation	2,615,000 dollars
Reactivation	180,000 dollars
Total	3,843,000 dollars

Expenditures ceased once the ship was put into actual commercial service, and it now represents earning capacity. Thus, even during the next few years, when so much more valuable operating experience will be gained, the "John Sergeant" will have an earning capacity and market value comparable to a "Liberty" ship.

As the former Chief of the Office of Ship Construction and Repair, U.S. Maritime Administration, Dr. J. J. McMullen was responsible for much of the above conversion scheme. He is now president of the Hudson Engineering Company, Hoboken, New Jersey, and we acknowledge his assistance in the preparation of this article.

Personal and Business

Appointments

MR. A. H. THOMAS has been elected chairman of the Purchasing Officers' Association.

MR. GEORGE F. FLATOW, A.M.I.Mech.E., has been appointed a director of Amber Oils, Ltd.

ALLDAYS AND ONIONS, Ltd., has announced the appointment of Mr. J. S. Erskine as sales manager.

MR. H. G. SHOWELL has been appointed registrar of Metal Industries, Ltd., in succession to the late Mr. J. Law.

THE ENGINEERING INSTITUTE OF CANADA has announced the appointment of Dr. Garnet T. Page as an assistant general secretary.

MR. E. C. MARTIN has been appointed chief development engineer to the Alexander Engineering Company, Ltd., Haddenham, Bucks.

VENNER ELECTRONICS, Ltd., has announced the appointment of Mr. J. A. Shelton as sales engineer, to handle its transistorised electronic equipment.

BOMA ENGINEERING (BILSTON), Ltd., has announced that Mr. E. W. Bold has been appointed sales executive and Mr. C. S. Fisher, London area representative.

THE CENTRAL ELECTRICITY AUTHORITY states that it has appointed Mr. A. Chorlton, A.M.I.E.E., to be system design and development engineer at the Authority's headquarters.

MR. ARTHUR L. BLOWER has been appointed chairman of Guy Motors, Ltd., Colonel Arthur Jerrett has been appointed managing director and Mr. Trevor Guy a director.

TURNER AND NEWALL, Ltd., has announced that Mr. R. M. Bateman, Mr. N. A. Morling, Mr. G. S. Sutcliffe and Mr. J. A. E. Clogg have been appointed to the board of directors.

TUBE INVESTMENTS, Ltd., states that Mr. E. L. Burton has been appointed secretary of the company in succession to Mr. I. N. Turner. Mr. Burton retains his responsibilities as chief accountant.

THE BRITISH TRANSPORT COMMISSION announces the following appointments: Mr. A. J. Ives, traffic costing officer (Great Northern Line); Mr. G. W. Hollowell, assistant, principal officer, and Mr. J. F. H. Tyler, assistant signal engineering officer.

LONDON TRANSPORT has announced that Mr. R. J. Hitchcock, labour relations officer, has been appointed a chief officer of the London Transport Executive, and that Mr. W. G. Randall has been appointed district superintendent of the south district of London Transport's country bus and coach services.

THE MINISTRY OF TRANSPORT AND CIVIL AVIATION has announced that Mr. R. J. Shepherd, M.I.N.A., has been appointed chief ship surveyor in succession to the late Mr. S. A. Hodges. Mr. H. H. Bath, M.I.N.A., has succeeded Mr. Shepherd as principal sea transport surveyor, and has in turn been succeeded as deputy chief ship surveyor at headquarters by Mr. D. R. M. Smith, M.I.N.A.

THE ADMIRALTY has announced that Rear-Admiral L. A. B. Peile has been appointed Admiral Superintendent, H.M. Dockyard, Devonport, in succession to Vice-Admiral I. N. Brownfield, and that the appointment will take effect in November. Rear-Admiral N. E. H. Clarke, A.M.I.Mech.E., has been appointed deputy director of dockyards (administration), in succession to Rear-Admiral L. A. B. Peile.

UNITED CONSTRUCTION MACHINERY COMPANY, Ltd., points out to us that some confusion may have been caused by our announcement in our Personal and Business columns on September 20 that it had been joined by Ruston-Bucyrus, Ltd., of Lincoln, Millars Machinery Company, Ltd., of Bishops Stortford; and Construction Machinery, Ltd., of Wakefield. It should be observed that United Construction Machinery Company, Ltd., is a combined sales organisation operating particularly in Eastern bloc countries.

Business Announcements

SIR WILLIAM HALCROW AND PARTNERS have opened an office at 10, Malone Road, Belfast (telephone, Belfast 660050).

JOHN BROWN AND CO., Ltd., has announced that the name of its subsidiary, Costain-John Brown, Ltd., has been changed to Constructors John Brown, Ltd.

THE HAWKER SIDDELEY GROUP has concluded an agreement whereby the Curtiss-Wright Corporation receives rights for the manufacture, sale and further development of the Orenda "Iroquois" in the United States of America. The agreement will run for seven years and provides also for the exchange of technical information. The engine, which was developed primarily for the Avro CF-105 "Arrow" interceptor, was illustrated on page 304, August 30 last.

ROTORK ENGINEERING COMPANY, Ltd., states that its address with effect from October 14 will be Widcombe Manor, Bath, Somerset (telephone, Bath 64558).

MR. C. W. SHARP, managing director of Electro-Hydraulics, Ltd., and Conveyancer Fork Trucks, Ltd., is leaving England on October 22 for a three months' world tour.

MR. I. TOWNSEND, clerk to the Traffic Commissioners and chief assistant to the Regional Transport Commissioner for Scotland, is to retire on October 31.

THE PLESSEY COMPANY, Ltd., has announced the formation of a subsidiary company, Rosite, Ltd., which will produce at its Swindon factory cold moulded plastics for use in the electrical industry.

THE NORTHERN IRELAND GOVERNMENT has announced that Mr. R. D. Duncan, M.I.C.E., chief engineer to the Northern Ireland Ministry of Health and Local Government, has retired. Lieut.-Col. C. P. Milway, A.M.I.C.E., has been appointed to succeed him.

SAMUEL OSBORN AND CO., Ltd., Sheffield, states that Mr. J. Williams, sales manager, and Mr. F. A. Kirk, metallurgist, have left this country to attend the study days of the Federation of European Petroleum Equipment Manufacturers, Stuttgart, Germany, October 9 to 12. They will deliver a paper entitled "Stainless Steels for the Petroleum Industry."

FOUNDRY EQUIPMENT AND L. AND Y. HOLDINGS, Ltd., has announced the formation of a subsidiary company in Canada entitled F.E. (North America), Ltd., for the purpose of handling the sales and servicing of the company's equipment and machines through agents in the U.S.A., and to assist its existing agents in Canada with sales and technical service. The address of the new subsidiary is 185, Eileen Avenue, Toronto, 9. Brigadier James Mess has been appointed president, and Mr. A. S. Beech, Mr. J. C. Howard and Mr. K. B. West directors.

ASSOCIATED COMMERCIAL VEHICLES, Ltd., is to set up a wholly owned subsidiary in the Federation of Rhodesia and Nyasaland, A.C.V. Central Africa (Pvt.), Ltd. Mr. Robert E. W. Holmes, formerly S.W. regional sales manager of A.C.V. Sales, Ltd., has been appointed a director and the general manager of the new firm, which will build a plant to assemble imported vehicles at Umtali, in the hinterland of Beira (Portuguese East Africa). First priority, however, will be given to establishing a spares and service organisation in the Central African Federation.

Contracts

A.C.V. SALES, Ltd., has announced the receipt of an order for 250 complete double-deck omnibuses, with maintenance spares, from the Teheran Omnibus Board. The chassis will be A.E.C. "Regent" Mark V with "Monocontrol" transmission and the bodies will be of Park Royal Vehicles construction. The total value of the order is approximately £2,500,000.

ROBERT WATSON AND CO. (CONSTRUCTIONAL ENGINEERS), Ltd., Bolton, has secured the contract for the only steel girder bridge in the Lancaster By-pass scheme, at Long Riddings. Of twenty-six bridges in the by-pass, twenty-five will be of prestressed concrete, but the twenty-sixth is to be a four-span bridge of steel girders in welded construction. Watson and Co. will erect this structure as subcontractors to Sir Lindsay Parkinson and Co., Ltd., the main contractor for the scheme.

G. AND J. WEIR, Ltd., Glasgow, has received a contract from the Crown Agents for Overseas Governments and Administrations for sea-water evaporating and distilling plant for the Clifton Pier power station of the Bahamas Electricity Corporation. The installation embodies two independent units, each of which produces more than 500,000 gallons of fresh water daily for domestic use, and a small quantity for supplying the power station boilers with de-aerated feed water. This order, worth more than £500,000, was obtained in international competition through the consultants, Messrs. Preece, Cardew and Rider, London. A feature of the equipment, the contractor states, is that it will be made largely of "Colclad" stainless steel in an entirely new design, and fabricated at the site. Each plant will have a main structure 32ft high, with internal compartments to form an eight-effect submerged-tube evaporating plant. The Bahamas plant is due to be completed in August, 1959.

Miscellanea

UNIVERSAL ADHESIVE.—A plastic adhesive and bonding agent for building and general industrial use has been introduced by Corrosion, Ltd., 16, Gloucester Place, London, W.1. Known as "Polybond," it is stated to be an effective binder for cement, concrete, bricks, plaster, asbestos, glass, metals, wood, most plastics, slates, building blocks, fabrics, &c. It is supplied in the form of an emulsion, which is thinned with cold water and, when set, it is stated to be waterproof, resistant to oil, grease, petrol, moulds and fungi, and a number of chemicals, whilst being clean and safe to handle, non-toxic and non-inflammable.

I.E.C. RECOMMENDATIONS FOR MERCURY ARC CONVERTERS.—The International Electrotechnical Commission has issued Publication No. 84, which gives recommendations for mercury arc converters with total rated power of at least 50kW, rated d.c. output of at least 10A, and rated d.c. voltage up to 5000V. The publication covers definitions and general information, tolerances, valves, converter transformers, and converters, and specifies various conditions affecting their design, manufacture and operation. Copies can be obtained (£1 14s. 9d. each) from the British Standards Institution Sales Branch, 2, Park Street, London, W.1.

BONDING RUBBER TO METAL.—Over the past few years Vacu-Lug Traction Tyres, Ltd., of Grantham, have developed a method of bonding rubber to metal. A wide variety of work has been undertaken, e.g. the rubberising of hooks for lifting concrete pipes; the building up of pneumatic tyre rims, to form solid tyres—this has been done chiefly for glassworks where pneumatic tyres were destroyed very rapidly; the rubberising of fan casings fitted to machines producing abrasive dust and particles; the rubber-to-metal bonding of track links; the reconditioning of rubber-covered tracks; the lining of casings for corrosive liquid pumps; and the rubberising of rollers fitted to agricultural harvesting machines.

HEAVY DUTY RAIL WAGONS.—A contract has been placed with Head Wrightson Teesdale, Ltd., a subsidiary of Head Wrightson and Co., Ltd., for the supply of two 102-ton transformer wagons suitable for running on a 3ft 6in gauge track, which are to be used in connection with the Kariba project. These wagons will be used for transporting transformers and other special loads over some 1000 miles of difficult country from the port of Beira to the site of the new Kariba hydro-electric scheme in the Federation of Rhodesia and Nyasaland. The wagons are carried on five-axle bogies, and their removable, well-type beams can be replaced by straight high-side beams when special loads are to be carried. Hydraulic jacks which are provided in the bolsters, are capable of raising the beams 1ft when they are loaded and removable crossbars are supplied between the well-beams for carrying the other general equipment required for the project. The maximum permissible axle load is 15 tons, and for this reason, together with the loading gauge restrictions, the five-axle bogies are of a special design with the inner three axleboxes at both ends fitted with sliding tops to allow for transverse movement when negotiating curves.

AIR-CONDITIONING PLANT.—There is now in production in this country by the Carrier Engineering Company, 24, Buckingham Gate, S.W.1, the "Weathermaster" system of air conditioning. This system distributes fresh air at relatively high pressures and, it is claimed, is comparable in total cost to a conventional heating system and mechanical ventilation in a building with many rooms. Because of the high air delivery pressure small ducts can be used; they can pass through the rooms and be concealed by decorative features; in each room a "Weathermaster" unit expands the delivery air through jets to entrain air already in the room and establish circulation. Each unit is provided with a water coil over which the entrained air passes and with supplies of heated and chilled water, enabling the temperature of the room to be adjusted. The water is supplied by a central plant with a heater and an absorption refrigerator. Outside air is drawn into the central air-conditioning plant through a rainproof louvre and screen. Filters remove entrained dust and dirt particles. In winter, this air is warmed by a preheater so that it absorbs moisture when passing through the humidifier sprays. During warm, humid weather a chilled water coil removes excess moisture from the air. In intermediate seasons a reheater warms the air sufficiently to offset building transmission losses. A high-pressure centrifugal fan delivers the air through small-diameter high-velocity conduits throughout the building, a sound absorber removing air noise as the air leaves the fan. An exhibition of the system will be held at the Mayfairia Rooms, Bryanston Street, W.1 from November 19 to 27.

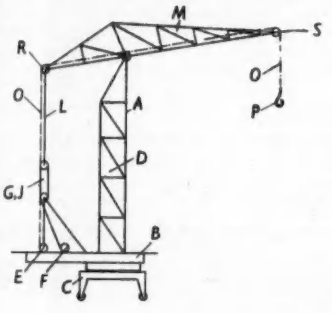
British Patent Specifications

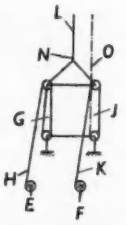
When an invention is communicated from abroad the name and address of the communicator are printed in italics. When an abridgment is not illustrated the specification is without drawings. The date first given is the date of application; the second date, at the end of the abridgment, is the date of publication of the complete specification. Copies of specifications may be obtained at the Patent Office Sales Branch, 15, Southampton Buildings, Chancery Lane, W.C.2, 3s. 6d. each.

CRANES AND LIFTING DEVICES

783,131. June 20, 1955.—LEVEL LUFFING JIB CRANE, Maschinenfabrik Augsburg-Nürnberg Aktiengesellschaft, Nürnberg, Germany.

The invention consists of a building crane with a luffing jib and a rope luffing gear including a pulley tackle in which, in order to ensure that the load describes an approximately level path, the lifting rope coming from the winch includes a pulley tackle with a fixed and a moving roller axis, whose moving roller axis is connected to the corresponding roller axis of the pulley tackle of the rope luffing gear, arranged parallel with the tackle of the lifting gear. The drawing shows a side view of a building crane, equipped with a beam jib extended beyond its fulcrum towards the rear. A tower *A* with the platform *B*, which can be turned together with the tower, are supported on the carriage *C* of the crane *D*. The luffing winch and lifting winch *E* and *F* are fixed on the platform. A pulley tackle *G* is arranged in the luffing rope *H* and another one *J* in the lifting rope *K*, and the lower roller axes of each of the pulley tackles are anchored to the platform *B*. The upper moving roller axes of the two pulley tackles can be coupled together or can form one complete unit, as shown in the lower view. These two roller axes are joined together in such a manner that although they can move up and down the axes will always remain at the same height and the luffing rope *L* leading towards the luffing jib *M* is then fixed to the joint *N*. The rope is shown diagrammatically, to improve the





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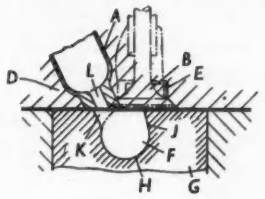
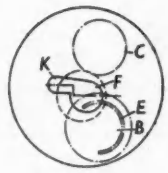
clarity of the representation. Actually, the resulting ropes are lying in the same plane. If the luffing jib *M* is also equipped with a rear jib, as shown in the upper view, the luffing rope will act at its end. If the crane is equipped with a beam-type jib *M*, as shown in the drawing, the lifting rope *O* carrying the load-hook *P* is guided over a roller *R* at the end of the luffing jib, and from there over another roller *S* on that end of the luffing jib which carries the load. Due to the connection between the moving roller axes of the two pulley tackles *G*, *J* the length of the lifting rope *O* is increased or reduced during each operation of the pulley tackle *G* of the luffing rope *L*, so that for each luffing position of the luffing jib *M* the load carried by the hook remains approximately at the same level if the lifting winch *F* is not operated at the same time.—*September* 18, 1957.

INTERNAL COMBUSTION ENGINES

783,053. February 28, 1956.—INJECTION-TYPE ENGINES, Daimler-Benz Aktiengesellschaft, Stuttgart-Untertürkheim, Germany.

The invention concerns improvements relating to injection-type internal combustion engines. As shown in the drawing, a precombustion chamber insert *A*, admission valve *B*, and exhaust valve *C* of an injection-type engine are disposed in the cylinder head *D*. The valve *B* carries a shield or screen *E* on one side. A main combustion chamber *F* approximately in the middle of the head of the piston *G* is composed of a spherical portion *H* and a small upwardly tapering conical portion *J*. A channel *K* open towards the top of the piston forms a prolongation of the discharge duct *L* of the precombustion chamber. It will be seen that the precombustion chamber is directed obliquely in relation to the longitudinal axis of the cylinder and opens by the duct *L* into the cylinder eccentrically in relation to the axis. As seen in side elevation, the duct *L* and the channel *K* are directed approximately tangentially of the main combustion chamber *F* and the channel affords to the jet issuing from the precombustion chamber straight unobstructed access to the combustion chamber. As seen in plan view, the channel *K* may be directed towards the middle of the main combustion chamber or it may open tangentially into the chamber in either direction, i.e. so that it gives the jet a whirling motion in either direction of rotation, as shown in the lower view. The combustion chamber



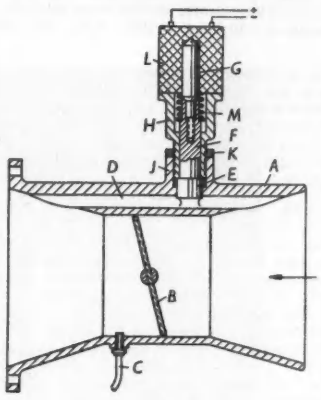


No. 783,053

F is arranged so that its longitudinal axis is inclined at about 15 deg. to 25 deg. towards one side with respect to the longitudinal axis of the cylinder, while the axis of the duct *L* is inclined at about 20 deg. to 30 deg. towards the opposite side with respect to the latter axis. The manner of operation is as follows: on the induction stroke, owing to the eccentric arrangement of the admission valve *B* in relation to the centre of the cylinder and owing to the shield *E* arranged on the valve, a whirling motion, in a clockwise direction, is imparted to the air flowing into the cylinder space. This whirling motion is maintained during the compression stroke and, towards the end of this stroke, is also propagated into the main combustion chamber *F* with, in fact, even increased intensity owing to the direction of the whirling motion being maintained constant. After the fuel has been injected into the precombustion chamber and ignition has been initiated, the still unburnt fuel particles pass, together with the remainder of the contents of the precombustion chamber, through the discharge duct *L* and channel *K* into the main combustion chamber *H*. Here, two whirling motions encounter one another, first the "horizontal" whirling motion of the air and secondly the "vertical" whirling motion of the contents of the precombustion chamber. Due to this double whirling motion, the individual particles are carried effectively to all parts of the combustion space, so that intimate mixing occurs and also all the oxygen particles in the combustion air really take part in the combustion process. Depending upon the given conditions of operation, the speed ranges, the conditions (pressure, temperature) of the combustion air, the penetrating power of the fuel jet issuing from the injection nozzle and so forth, it may be advantageous, for obtaining intimate mixing of all the particles, to arrange the channel *K* so that it by itself impresses upon the contents of the precombustion chamber a whirling motion in one or the other direction in a transverse plane of the cylinder or so that it does not influence the whirling motion in this plane.—*September* 18, 1957.

783,247. March 20, 1956.—THE PREVENTION OF AFTER-RUNNING, Daimler-Benz Aktiengesellschaft, Stuttgart-Untertürkheim, Germany.

The invention concerns improvements relating to the prevention of after-running of injection-type internal combustion engines. The drawing represents an axial section through the length *A* of induction passage in which is the throttle valve *B* of a fuel-injection engine with extraneous ignition by sparking plugs. The pressure prevailing downstream of the valve is conducted through a duct *C* to the regulator which controls the quantity of fuel injected. The sole slow-running air passage *D* by-passing the valve *B* and conducting pure combustion air only, not fuel or mixture, can be shut off by a valve unit in a housing on the passage. The valve unit comprises the valve proper in the form of a cylindrical sliding piston *E*, a guide stem *F* and a magnet core *G*. A bushing *H* is screwed into an eye *J* formed on the wall and is secured at a preset depth by a locknut *K*. The bushing *H* carries an electromagnet *L* whose exciting circuit is controlled, together with the ignition circuit of the engine. A compression spring *M* tends to press the valve *E* into the closed position, but its force can be overcome by the upward attraction of the magnet *L* on the core *G*. In the slow running



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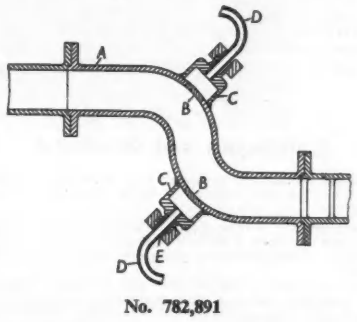
position illustrated, the throttle valve *B* is tightly closed. For internal combustion engines working with fuel-injection, tight closing of the throttle valve must be ensured, as incorrect pressures would otherwise be produced in the regulating duct *C*. When ignition current for the engine is switched on, current is also supplied to the magnet, which lifts the valve *E*. Depending upon the depth to which the bushing *H* has been screwed in, the slow-running passage is thus opened to a greater or lesser degree, so that the slow-running speed of the engine can be adjusted. When the ignition is switched off, the magnet *L* is de-energised and the valve *E* is forced down by the spring *M* so that it completely closes the slow-running passage *D*. The engine cannot then continue to run, even if there are incandescent points in the combustion chamber, because the air necessary for combustion is no longer supplied.—*September* 18, 1957.

GAS TURBINES

782,891. May 23, 1952.—COOLING GAS TURBINES, The Birmingham Small Arms Company, Ltd., Armoury Works, Armoury Road, Small Heath, Birmingham, 11. (*Inventor: Donald Arthur Oliver.*)

The invention relates to gas turbines in which parts are subject to high temperatures and are difficult to cool. According to the invention, in a gas turbine means for cooling a part made of non-porous material comprises a piece or pieces of porous metal inserted in the part and surrounded by a cover plate or casing connected to a source of supply of cooling fluid.



No. 782,891

In the construction shown in the drawing, a flame tube connector *A* is constructed so that the part of the bend which becomes hottest consists of an inserted panel of porous heat and scale resisting metal *B* secured to the remainder of the connector, which is in the form of stainless steel casting, by the process described in Patent Specification No. 691,983. Surrounding the porous insert *B* is a cap *C* welded to the main body of the connector. When in operation, the part of the elbow most subjected to heating is cooled to a high degree by compressed air passing through the pipe *D* on to the porous insert *B*. As soon as one side of the elbow is held permanently, due to sweat cooling, at a lower temperature than the other side of the elbow, it will form a heat sink and therefore tend to extract heat from the adjoining solid parts of the structure. Two modified constructions are also shown in the specification.—*September* 18, 1957.

Launches and Trial Trips

NETTA CROAN, trawler; built by John Lewis and Sons, Ltd., for Joe Croan, Ltd.; length overall 130ft, breadth 25ft, depth 12ft, gross tonnage 268 tons, fish room 6700 cubic feet; electric trawl winch 1000 fathoms of 2¾in warp; one 121kW diesel-driven trawl winch generator, one 20kW and one 10kW diesel-driven generators; British Polar Mark M.44.M. diesel engine, 640 b.h.p. at 250 r.p.m. Trial, August 14.

ESSO GLASGOW, oil tanker; reconstruction by Harland and Wolff, Ltd., at Belfast, for the Esso Petroleum Company, Ltd.; length overall 523ft 6in, length between perpendiculars 503ft, breadth moulded 68ft, depth moulded 39ft 3in, deadweight 16,000 tons on 30ft 2in draught new centre section. Trial, August 19.

PEGASUS, cargo ship; built by the Furness Shipbuilding Company, Ltd., for the Sociedad Transoceania Canopus S.A., Panama; length overall 518ft 1in, length between perpendiculars 480ft, breadth moulded 66ft, depth moulded to upper deck 42ft 6in, deadweight 16,200 tons, capacity 817,944 cubic feet, summer draught 31ft 5½in; five holds, derrick complement ranges from 2 tons to 30 tons, electric winches; three 150kW diesel-driven generators; one 50kW steam-driven generator; N.E.M.-Doxford oil engine, five cylinders, 670mm diameter by 2320mm combined stroke, 5500 b.h.p. at 115 r.p.m., trial speed at ballast draught 15·41 knots. Trial, August 20.

MENESTHEUS, cargo liner; built by the Caledon Shipbuilding and Engineering Company, Ltd., for Alfred Holt and Co.; length overall 495ft, breadth moulded 65ft, depth moulded to upper deck 36ft, deadweight 9800 tons, sea speed 15 knots; five cargo holds, one 35-ton, two 15-ton, six 10-ton, eighteen 5-ton derricks, and one 7-ton, to serve the engine room, electric winches; two 450kW diesel-driven generators, one 250kW diesel-driven emergency generator; exhaust turbo-pressure-charged, single-acting, opposed piston, diesel engine, 8000 b.h.p. at 112 r.p.m. Trial, August 26.

KATSINA PALM, cargo ship; built at the Neptune Works of Swan, Hunter and Wigham Richardson, Ltd., for the Palm Line, Ltd.; length between perpendiculars 469ft, breadth moulded 62ft 6in, depth moulded to shelter deck 35ft 9in, deadweight 11,200 tons on 26ft 6in draught; five holds, one 50-ton, four 15-ton, two 10-ton, ten 5-ton, and two 3-ton derricks, electric winches; three 250kW diesel-driven generators, one 30kW emergency generator; Swan, Hunter-Doxford oil engine, five cylinders, 670mm diameter by 2320mm combined stroke, 5600 b.h.p. at 117 r.p.m. Launch, August 26.

CHIRRIPO, banana carrier and passenger liner; built by Alexander Stephen and Sons, Ltd., for Elders and Fyffes, Ltd.; length between perpendiculars 390ft, breadth moulded 56ft 6in, depth to upper deck 35ft; twelve passengers; fourteen insulated cargo spaces, eight 5-ton derricks serve four holds, electric winches; two 450kW geared turbo-generators, one 400kW diesel-driven generator, one 60kW diesel-driven emergency generator; one set of two-cylinder, double reduction geared turbines take steam at 500 lb per square inch and 790 deg. Fah. from two Babcock and Wilcox single-pass boilers. Launch, August 26.

Catalogues and Brochures

RAMSEN ENGINEERING COMPANY, Ltd., Hythe Road, London, N.W.10.—Illustrated leaflet giving details of a range of mobile conveyors.

RANSOMES AND RAPIER, Ltd., Waterside Works, Ipswich.—Catalogue illustrating a standard range of shovels, drag shovels, skimmers, cranes, draglines, grabs, pile drivers and walking draglines.

W. G. BAGNALL, Ltd., Castle Engine Works, Stafford.—A pamphlet illustrating diesel locomotives manufactured by this company; brief specifications of some recently delivered types are included.

LANGLEY ALLOYS, Ltd., Langley, Slough, Bucks.—Leaflet dealing with hidurax aluminium bronze valves. A selection of valves are dealt with in the leaflet, gate valves, Y-type valves, globe valves and check valves.

NATURAL ASPHALTE MINE-OWNERS and MANUFACTURERS COUNCIL, 94/98, Petty France, Westminster, London, S.W.1.—Booklet entitled "The Story of Asphalte in Building," directed primarily to students of the architectural, engineering and surveying professions, and of the building industry, giving an up-to-date explanation of what asphalte is and of its value in building.

FERODO, Ltd., Chapel-en-le-Frith, Stockport.—The new edition of the Ferodo motor trade catalogue is divided into six main sections, brake linings, replacement brake shoes, clutch facings, clutch plates, fan belts and rivets, tools and miscellaneous products. A price list has been included as a separate booklet. A pictorial guide at the beginning of the catalogue includes a section on Ferodo friction materials for disc brakes.

ENGLISH ELECTRIC COMPANY, Ltd., Meter, Relay and Instrument Division, Stafford.—Four leaflets describing some of the company's recently introduced instruments. The titles of the leaflets are: "Rotary Synchroscopes," "Switchboard Instruments, Moving Iron Type, Round, Flush and Projecting Pattern," "Switchboard Instruments, Moving Iron Type, Square, Flush Mounting Pattern," and "Portable Current Density Indicator."

WHITEHOUSE INDUSTRIES, Ltd., Philidas Division, Ferrybridge, Knottingley, Yorkshire.—Catalogue illustrating and describing Philidas self-locking nuts. Details are given of the applications of these nuts, and also details of tests made on the nuts are included, such as efficiency tests, bolt tolerance tests, temperature tests, and also unscrewing torque data; an aircraft conversion chart is included at the end.

BRITISH INSULATED CALLENDER'S CABLES, Ltd., 21, Bloomsbury Street, London, W.C.1.—New comprehensive catalogue, totalling about 320 pages, which covers the entire range of the company's overhead line materials, and comprises a binder containing six individual sections, dealing with the following subjects:—copper and cadmium-copper conductors; steel-cored aluminium conductors; hard-drawn aluminium conductors; poles, pole line fittings, insulators and tools (in this section there is also catalogued the overhead line equipment for both high and low voltages; P.B. poles; overhead line installations.

Forthcoming Engagements

Secretaries of Institutions, Societies, &c., desirous of having notices of meetings inserted in this column, are requested to note that, in order to make sure of their insertion, the necessary information should reach this office not later than a fortnight before the meeting. In all cases the TIME *and* PLACE *at which the meeting is to be held should be clearly stated.*

ASSOCIATION OF SUPERVISING ELECTRICAL ENGINEERS

To-day, Oct. 11.—STOKE AND CREWE BRANCH: Grand Hotel, Hanley, Stoke, "Earth Leakage Protection of Domestic and Similar Installations," J. A. Robbins, 7.30 p.m.
Mon., Oct. 14.—CENTRAL LONDON BRANCH: White Hall Hotel, Bloomsbury Square, W.C.1, "Isotopes," F. H. Gottfield, 6.30 p.m.
Wed., Oct. 16.—S.W. LONDON BRANCH: Visit to the B.B.C. Television Studios, Lime Grove, 2.30 p.m.
Thurs., Oct. 17.—KENT BRANCH: St. Mildred's Hotel, Westgate, Thanet, Film Show, 7.30 p.m.
Sat., Oct. 19.—OXFORD, READING AND DISTRICTS BRANCH: Regent's Park College, Pusey Street, Oxford, "The Work of the National Inspection Council for Electrical Installation Contracting," E. J. Sutton, 7 p.m.

COMBUSTION ENGINEERING ASSOCIATION

Wed., Oct. 16.—St. Ermin's Hotel, London, S.W.1, "A Survey of Boiler Cleaning Methods," R. H. Thompson, 10.30 a.m. "Planning the Installation of New Boiler Plant," G. H. Buckle, 2.30 p.m.

ILLUMINATING ENGINEERING SOCIETY

Mon., Oct. 14.—SHEFFIELD CENTRE: Grand Hotel, Sheffield, Chairman's Address, F. Smith, 6.30 p.m.
Tues., Oct. 15.—LIVERPOOL CENTRE: Liverpool Passenger Transport Office, 24, Hatton Garden, Liverpool, 3, Chairman's Address, W. B. Parkinson, 6 p.m.
Wed., Oct. 16.—TEES-SIDE GROUP: Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, "Interior Decorating and Lighting," L. Wilson, 6.30 p.m.
Thurs., Oct. 17.—MANCHESTER CENTRE: N.W. Electricity Board, Town Hall, Manchester, 2, "The Stage and the Lighting Engineer," F. B. Bentham, 6 p.m.

INSTITUTE OF BRITISH FOUNDRYMEN

Tues., Oct. 15.—EAST ANGLIAN SECTION: Lecture Hall, Public Library, Ipswich, Induction of President, R. E. Berry, Presidential Address and Paper, 7.30 p.m.

INSTITUTE OF MARINE ENGINEERS

Mon., Oct. 14.—STUDENT MEETING: Memorial Building, 76, Mark Lane, London, E.C.3, Films, "Super Tanker" and "Foothold on Antarctica," 6.30 p.m.

INSTITUTE OF NAVIGATION

Wed., Oct. 16.—Royal Geographical Society, 1, Kensington Gore, London, S.W.7, Annual General Meeting, Presidential Address, "The Display and Use of Navigational Intelligence," A. M. A. Majendie, 3 p.m.

INSTITUTE OF PETROLEUM

Wed., Nov. 6.—26, Portland Place, London, W.1, "The Impact of Cyclical Fluctuations on Fuel Oil Demand," G. Chandler and D. W. Lindsell, 5.30 p.m.

INSTITUTE OF PHYSICS

Tues., Oct. 15.—ELECTRONICS GROUP: 47, Belgrave Square, London, S.W.1, "Dense Electron Beams," B. Meltzer, 5.30 p.m.
Wed., Oct. 16.—N.E. BRANCH: Science Laboratories, South Road, Durham, "Ferromagnetism and Magnetic Materials," A. E. De Barr, 5.45 p.m. ★ YORKSHIRE BRANCH: Physics Department, The University, Leeds, "Nuclear Magnetic Resonance in Solids," E. R. Andrew, 3 p.m.
Fri., Oct. 18.—S. WALES BRANCH: Physics Department, University College of South Wales and Monmouthshire, Cardiff, "Structural and Physical Properties of Alloys," H. Jones, 5.15 p.m. ★ NON-DESTRUCTIVE TESTING GROUP: 47, Belgrave Square, London, S.W.1, "Nuclear Magnetic and Paramagnetic Resonance," L. E. Drain, 6 p.m.

INSTITUTE OF ROAD TRANSPORT ENGINEERS

To-day, Oct. 11.—W. CENTRE: Rougemont Hotel, Exeter, "High Pressure and Syndromic Lubrication Systems," W. T. Kay, 7 p.m. ★ S. WALES CENTRE: Visit to the works of Guest, Keen Iron and Steel Company, East Moors, Cardiff, 2.15 p.m. ★ S. WALES CENTRE: South Wales Institute of Engineers, Park Place, Cardiff, "The Operation and Development of Disc Brakes," T. J. Phipps, 7 p.m.
Tues., Oct. 15.—W. REGIONAL CENTRE: Liverpool Architectural Society's Rooms, Bluecoat Chambers, School Lane, Liverpool, 1, "The Design and Construction of a Modern Goods Carrying Vehicle," A. S. C. Marks, 7.30 p.m. ★ N.E. CENTRE: Three Tuns Hotel, Durham, "Research on the Testing and Performance of Commercial Vehicle Brakes," R. D. Lister, 7.30 p.m.
Thurs., Oct. 17.—YORKSHIRE CENTRE: Great Northern Hotel, Willington Street, Leeds, 1, "Oil Engine Injectors and their Maintenance," T. G. Charlesworth, 7.30 p.m.

INSTITUTION OF BRITISH AGRICULTURAL ENGINEERS

Tues., Oct. 15.—6, Buckingham Gate, London, S.W.1, Presidential Address, J. M. Chambers, 5 p.m.

INSTITUTION OF CHEMICAL ENGINEERS

Tues., Oct. 15.—N.W. BRANCH: College of Science and Technology, Manchester, "Liquefaction of Hydrogen on a Commercial Scale—Technological Problems and Economics," W. L. Seddon, 7 p.m.

INSTITUTION OF CIVIL ENGINEERS

Tues., Oct. 15.—Great George Street, Westminster, London, S.W.1, "An Investigation into a Proposal to Dispose of Power Station Ash by Discharging it into the Sea at Low Water," F. L. Harwood and K. C. Wilson, 5.30 p.m.

INSTITUTION OF ELECTRICAL ENGINEERS

Mon., Oct. 14.—INFORMAL MEETING: Savoy Place, London, W.C.2, Discussion on "The Social Consequences of Automation," to be opened by the President, 5.30 p.m. ★ N.E. CENTRE: Neville Hall, Newcastle upon Tyne, Chairman's Address, T. W. Wilcox, 6.15 p.m. ★ N. STAFFORDSHIRE SUB-CENTRE: Jubilee Hall, Stoke-on-Trent, Chairman's Address, H. A. P. Caddell, 7 p.m. ★ WESTERN CENTRE: South Wales Institute of Engineers, Cardiff, Chairman's Address, J. F. Wright, 6 p.m.
Tues., Oct. 15.—LONDON GRADUATE AND STUDENT SECTION: Assembly Hall, 3 (Tels.) Training Bn., R.E.M.E., Arborfield, Berks, Repeat of Chairman's Address, F. L. Fielding, 7 p.m. ★ N. MIDLAND CENTRE: Central Electricity Authority, Yorkshire Division, 1, Whitehall Road, Leeds, "Electrical Equipment for Rectifier Locomotives," H. B. Calverley, E. A. K. Jarvis and E. Williams, 6.30 p.m. ★ N.W. SUPPLY GROUP: Engineers' Club, Albert Square, Manchester, "Experiences in the U.S.S.R.," H. West, 6.15 p.m. ★ S.E. SCOTLAND SUB-CENTRE: Carlton Hotel, North Bridge, Edinburgh, Sub-Centre Chairman's Address, J. Mendelson, 7 p.m. ★ S.W. SCOTLAND SUB-CENTRE: Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, Sub-Centre Chairman's Address, A. J. Small, 7 p.m.
Wed., Oct. 16.—RADIO AND TELECOMMUNICATION SECTION: Savoy Place, London, W.C.2, Chairman's Address, "Some Radio Aids for High-Speed Aircraft," J. S. McPetrie, 5.30 p.m. ★ SHEFFIELD SUB-CENTRE: Grand Hotel, Sheffield, Chairman's Address, O. I. Butler, 6.30 p.m. ★ SOUTHERN CENTRE: Brighton Technical College, "Electrical Floor Warming," I. W. Moule and W. M. Stevenson, 6.30 p.m.
Thurs., Oct. 17.—LONDON GRADUATE AND STUDENT SECTION: Staff Canteen, D. Napier and Son, The Airport, Luton, Repeat of Chairman's Address, F. L. Fielding, 7 p.m.
Fri., Oct. 18.—EDUCATION DISCUSSION CIRCLE: Savoy Place, London, W.C.2, Discussion on "The Architectural Features of Electrical Engineering Laboratories," opened by H. E. Dance and P. F. Soper, 6 p.m.

INSTITUTION OF ENGINEERING DESIGNERS

Mon., Oct. 14.—N.E. BRANCH: Northern Architectural Association Hall, 6, Higham Place, Newcastle upon Tyne, "Building Structures," G. Gladstone, 7.15 p.m.

INSTITUTION OF ENGINEERS IN CHARGE

Fri., Oct. 25.—Caxton Hall, Caxton Street, Westminster, London, S.W.1, Presidential Address, Sir Harold Roxbee Cox, 6.30 p.m.

INSTITUTION OF MECHANICAL ENGINEERS

Tues., Oct. 15.—AUTOMOBILE DIVISION: 1, Birdcage Walk, Westminster, London, S.W.1, Discussion on "The Effect of Modern Design on Repair Costs," 6.45 p.m. ★ EASTERN BRANCH: Good Companions Hotel, Slough, "The Channel Tunnel Project," Christopher Shawcross, 7.30 p.m.
Wed., Oct. 16.—YORKSHIRE BRANCH: Royal Station Hotel, Hull, "Modern Blast Furnaces," M. Adamson, 7.30 p.m.
Thurs., Oct. 17.—E. MIDLANDS GRADUATES' SECTION: College of Further Education, Green Close Lane, Loughborough, "The Auris 1200 h.p. B.T.H. Gas Turbine," B. L. Birts and R. M. Duggan, 7.15 p.m. ★ YORKSHIRE GRADUATES' SECTION: Hotel Metropole, Leeds, "Introduction of a New Product into Production," D. K. Woodward, 6.30 p.m.
Fri., Oct. 18.—GENERAL MEETING: 1, Birdcage Walk, Westminster, London, S.W.1, Presidential Address, Sir George Nelson, 6 p.m.

INSTITUTION OF MINING AND METALLURGY

Thurs., Oct. 17.—GENERAL MEETING: Geological Society, Burlington House, Piccadilly, London, W.1, "Control of Air Pressure as an Aid to Fight Mine Fires," J. M. Caw, and "The Production of Zinc in a Blast Furnace," S. W. K. Morgan, 5 p.m.

INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

Tues., Oct. 15.—ORDINARY MEETING: Institution of Electrical Engineers, Savoy Place, London, W.C.2, Chairman's Address, "30 Years of Radio Development in the Post Office," H. G. Beer, 5 p.m.

INSTITUTION OF PRODUCTION ENGINEERS

Tues., Oct. 15.—TEES SIDE SECTION: College of Further Education, Cleveland Avenue, Darlington, "Heavy Forging," R. C. Benson, 7 p.m. ★ LONDON GRADUATE SECTION: 10, Chesterfield Street, W.1, "Nylon Moulding," 7.15 p.m.
Wed., Oct. 16.—EAST AND WEST RIDINGS SECTION: George Hotel, Huddersfield, "Selecting the Right Man for the Job—A Review of Modern Procedures," T. M. Higham, 7.30 p.m. ★ MIDLANDS REGION: James Watt Memorial Institute, Great Charles Street, Birmingham, "The Technique of Tube Making," L. C. Hackett, 7 p.m. ★ WOLVERHAMPTON SECTION: College of Technology, Wulfruna Street, Wolverhampton, "Practical Research into Machining Problems," J. Cherry, 7.15 p.m.
Thurs., Oct. 17.—GLASGOW SECTION: Institution of Engineers and Shipbuilders, 39, Elmbank Crescent, Glasgow, "Electronic Instrumentation," 7.30 p.m. ★ LONDON SECTION: Royal Empire Society, Northumberland Avenue, Strand, W.C.2, "Electronics as an Aid to Production," T. A. Waite, 7.15 p.m. ★ LUTON SECTION: Staff Canteen, S.K.F., Ltd., Luton, "A New Approach to Production Control," J. L. Burbidge, 7.30 p.m.

INSTITUTION OF PUBLIC HEALTH ENGINEERS

Thurs., Oct. 17.—SESSIONAL MEETING: Caxton Hall, Westminster, London, S.W.1, "The Removal of Sulphur Dioxide from Chimney Flue Gases," A. Parker, 6 p.m.

JUNIOR INSTITUTION OF ENGINEERS

To-day, Oct. 11.—ORDINARY MEETING: Pepys House, 14, Rochester Row, Westminster, London, S.W.1, "The Microscope in Engineering," Arthur E. Bingham, 7 p.m.
Mon., Oct. 14.—SHEFFIELD AND DISTRICT SECTION: Livesey Clegg House, 44, Union Street, Sheffield, 1, Annual General Meeting, Chairman's Address, "Vehicle Recovery," T. F. Bailey, 7.30 p.m.
Fri., Oct. 18.—INFORMAL MEETING: Pepys House, 14, Rochester Row, Westminster, London, S.W.1, "Sub-Standard Films," W. C. C. Ball, 7 p.m.

NORTH EAST COAST INSTITUTION OF ENGINEERS AND SHIPBUILDERS

Fri., Oct. 18.—Literary and Philosophical Society, Newcastle upon Tyne, Film on M.V. "Bergensfjord," Opening General Meeting, 6.15 p.m.

PLASTICS INSTITUTE

To-day, Oct. 11.—N.W. SECTION: Engineers' Club, Albert Square, Manchester, Technical Film Evening, 6.45 p.m.

REINFORCED CONCRETE ASSOCIATION

Wed., Oct. 16.—11, Upper Belgrave Street, London, S.W.1, "The Structural Design of Reinforced Concrete Biological Shields," P. A. Badland, 6 p.m.

ROYAL INSTITUTION OF CHARTERED SURVEYORS

Wed., Oct. 16.—QUANTITY SURVEYORS GENERAL MEETING: 12, Great George Street, London, S.W.1, Discussion on "The Return to Fixed Price Tendering," opened by J. T. A. Brocks, 6 p.m.